RECEIPT # 66186
AMOUNT $ 250.00
SUMMONS ISSUED yes
LOCAL RULE 4.1
WAIVER FORM
MCF ISSUED
AO 120 OR 121
BY DPTY CLK
DATE 8-11-05

UNITED STATES DISTRICT COURT
DISTRICT OF MASSACHUSETTS

FURUKAWA ELECTRIC NORTH AMERICA, INC.; and OFS FITEL LLC, Plaintiffs, vs. ANTARES DEVELOPMENT INTERNATIONAL LLC, Defendant.	Civil Action No. JURY TRIAL DEMANDED Referred to MJ RB Collings

COMPLAINT

NATURE OF THE ACTION

1. Plaintiffs Furukawa Electric North America, Inc. ("FENA") and OFS Fitel LLC ("OFS") (collectively "Plaintiffs"), for their complaint for patent infringement against Defendant Antares Development International, LLC ("Antares"), hereby allege as follows. This is an action for patent infringement arising under the Patent Laws of the United States, Title 35, United States Code.

PARTIES

2. Plaintiff FENA is a Delaware corporation with its principal place of business in Norcross, Georgia.

3. Plaintiff OFS is a Delaware limited liability company with its principal place of business in Norcross, Georgia. OFS is a wholly-owned subsidiary of FENA.

4. On information and belief, Defendant Antares is a limited liability corporation organized under the laws of Massachusetts with a principal place of business in Sturbridge, Massachusetts. *See* Declaration of Crawford Cutts ("Cutts Decl."), ¶ 2-3 (attached hereto as *Exhibit* A).

JURISDICTION AND VENUE

5. This is an action for patent infringement arising under the Patent Laws of the United States, Title 35, United States Code. The Court has jurisdiction under 28 U.S.C. §§ 1331, 1338 and 35 U.S.C. § 271.

6. This Court has personal jurisdiction over Antares by virtue of its activities within this district constituting infringement of the patents identified herein.

7. Venue is proper in this district under 28 U.S.C. §§ 1391 (b), (c) and 1400 (b).

FACTUAL BACKGROUND

Jurisdictional Facts

8. Plaintiffs are in the business of, among other things, developing, manufacturing and selling optical fiber products.

9. Antares is in the business of selling and/or offering for sale optical fiber products manufactured by Yangtze Optical Fiber and Cable Company Ltd. ("YOFC"). *See* Cutts Decl., ¶ 7.

10. On information and belief, YOFC exports its products from China into the United States. A copy of a January 24, 2005 press release describing YOFC's activities is attached as Exhibit B.

11. On information and belief, In January of 2005, YOFC appointed Antares as its exclusive agent, responsible for sales, marketing and technical operations in North America.

Since that time, Antares has in fact been attempting to sell YOFC's products within the United States. *See* Cutts Decl., ¶ 7.

12. On information and belief, Antares and YOFC, have offered to sell certain of YOFC's infringing products to one or more customers in Massachusetts.

13. On information and belief, in the first half of 2005, Antares and YOFC offered YOFC's infringing fiber optic products for sale at one or more conferences or trade shows, including but not limited to, the BICSI 2005 Spring Conference in Las Vegas, Nevada, and the January, 2005 BICSI conference in Orlando, Florida.

The Patents

14. On April 11, 1989, U.S. Patent No. 4,820,322 ("'322 patent") was duly issued for an invention entitled "Method of and Apparatus for Overcladding a Glass Rod." A copy of the '322 patent is attached as Exhibit C and is made a part of this Complaint. FENA is the owner by assignment of all right, title and interest in the '322 patent, with full and exclusive rights to bring suit to enforce the '322 patent. OFS is the exclusive licensee under the '322 patent.

15. On May 20, 1990, U.S. Patent No. 4,909,816 ("'816 patent") was duly issued for an invention entitled "Optical Fiber Fabrication and Resulting Product." A copy of the '816 patent is attached as Exhibit D and is made a part of this Complaint. FENA is the owner by assignment of all right, title and interest in the '816 patent, with full and exclusive rights to bring suit to enforce the '816 patent. OFS is the exclusive licensee under the '816 patent.

16. On March 29, 1996, U.S. Patent No. 5,298,047 ("'047 patent") was duly issued for an invention entitled "Method of Making a Fiber Having Low Polarization Mode Dispersion Due to a Permanent Spin." A copy of the '047 patent is attached as Exhibit E and is made a part of this Complaint. FENA is the owner by assignment of all right, title and interest in the

'047 patent, with full and exclusive rights to bring suit to enforce the '047 patent. OFS is the exclusive licensee under the '047 patent.

17. On May 23, 1995, U.S. Patent No. 5,418,881 ("'881 patent") was duly issued for an invention entitled "Article Comprising Optical Fiber Having Low Polarization Mode Dispersion, Due to Permanent Spin." A copy of the '881 patent is attached as Exhibit F and is made a part of this Complaint. FENA is the owner by assignment of all right, title and interest in the '881 patent, with full and exclusive rights to bring suit to enforce the '881 patent. OFS is the exclusive licensee under the '881 patent.

CLAIMS FOR RELIEF

COUNT ONE
(Infringement of the '322 Patent)

18. Plaintiffs incorporate by reference and reallege the averments of paragraphs 1 through 17, as if fully set forth herein.

19. Antares has been and still is infringing the '322 patent by offering to sell, importing and/or selling within the District of Massachusetts, and elsewhere in the United States, the invention of at least one claim of the '322 patent and has, therefore, infringed and is infringing the '322 patent, either directly or under the doctrine of equivalents, and Antares will continue to do so unless enjoined by the Court.

20. On information and belief, Antares actively has induced and continues to induce others to infringe the '322 patent by actively promoting use of YOFC's infringing products.

21. Upon information and belief, Antares' infringement of the '322 patent has been and continues to be willful and deliberate and with full knowledge of Plaintiffs' patent rights. Antares' willful conduct makes this an exceptional case as provided in 35 U.S.C. § 285.

22. Antares' willful conduct provides a basis for this Court to award enhanced damages, including up to treble damages as provided by 35 U.S.C. § 284.

23. Antares' infringement of the '322 patent has caused and will continue to cause damage and irreparable injury to Plaintiffs, for which there is no adequate remedy at law. Unless enjoined by this Court, Antares will continue its acts of infringement to Plaintiffs' substantial and irreparable damage.

COUNT TWO
(Infringement of the '816 Patent)

24. Plaintiffs incorporate by reference and reallege the averments of paragraphs 1 through 23, as if fully set forth herein.

25. Antares has been and still is infringing the '816 patent by offering to sell, importing and/or selling within the District of Massachusetts, and elsewhere in the United States, the invention of at least one claim of the '816 patent and has, therefore, infringed and is infringing the '816 patent, either directly or under the doctrine of equivalents, and Antares will continue to do so unless enjoined by the Court.

26. On information and belief, Antares actively has induced and continues to induce others to infringe the '816 patent by actively promoting use of YOFC's infringing products.

27. Upon information and belief, Antares' infringement of the '816 patent has been and continues to be willful and deliberate and with full knowledge of Plaintiffs' patent rights. Antares' willful conduct makes this an exceptional case as provided in 35 U.S.C. § 285.

28. Antares' willful conduct provides a basis for this Court to award enhanced damages, including up to treble damages as provided by 35 U.S.C. § 284.

29. Antares' infringement of the '816 patent has caused and will continue to cause damage and irreparable injury to Plaintiffs, for which there is no adequate remedy at law. Unless

enjoined by this Court, Antares will continue its acts of infringement to Plaintiffs' substantial and irreparable damage.

COUNT THREE
(Infringement of the '047 Patent)

30. Plaintiffs incorporate by reference and reallege the averments of paragraphs 1 through 29, as if fully set forth herein.

31. Antares has been and still is infringing the '047 patent by offering to sell, importing and/or selling within the District of Massachusetts, and elsewhere in the United States, the invention of at least one claim of the '047 patent and has, therefore, infringed and is infringing the '047 patent, either directly or under the doctrine of equivalents, and Antares will continue to do so unless enjoined by the Court.

32. On information and belief, Antares actively has induced and continues to induce others to infringe the '047 patent by actively promoting use of YOFC's infringing products.

33. Upon information and belief, Antares' infringement of the '047 patent has been and continues to be willful and deliberate and with full knowledge of Plaintiffs' patent rights. Antares' willful conduct makes this an exceptional case as provided in 35 U.S.C. § 285.

34. Antares' willful conduct provides a basis for this Court to award enhanced damages, including up to treble damages as provided by 35 U.S.C. § 284.

35. Antares' infringement of the '047 patent has caused and will continue to cause damage and irreparable injury to Plaintiffs, for which there is no adequate remedy at law. Unless enjoined by this Court, Antares will continue its acts of infringement to Plaintiffs' substantial and irreparable damage.

COUNT FOUR
(Infringement of the '881 Patent)

36. Plaintiffs incorporate by reference and reallege the averments of paragraphs 1 through 35, as if fully set forth herein.

37. Antares has been and still is infringing the '881 patent by offering to sell, importing and/or selling within the District of Massachusetts, and elsewhere in the United States, the invention of at least one claim of the '881 patent and has, therefore, infringed and is infringing the '881 patent, either directly or under the doctrine of equivalents, and Antares will continue to do so unless enjoined by the Court.

38. On information and belief, Antares actively has induced and continues to induce others to infringe the '881 patent by actively promoting use of YOFC's infringing products.

39. Upon information and belief, Antares' infringement of the '881 patent has been and continues to be willful and deliberate and with full knowledge of Plaintiffs' patent rights. Antares' willful conduct makes this an exceptional case as provided in 35 U.S.C. § 285.

40. Antares' willful conduct provides a basis for this Court to award enhanced damages, including up to treble damages as provided by 35 U.S.C. § 284.

41. Antares' infringement of the '881 patent has caused and will continue to cause damage and irreparable injury to Plaintiffs, for which there is no adequate remedy at law. Unless enjoined by this Court, Antares will continue its acts of infringement to Plaintiffs' substantial and irreparable damage.

PRAYER FOR RELIEF

WHEREFORE, Plaintiffs pray for judgment and relief against Antares as follows:

A. For an Order adjudging Antares to have infringed one or more claims of the '322, '816, '047, and '881 patents under 35 U.S.C. § 271;

B. For an Order enjoining any further infringement by Antares, its officers, agents, servants, employees, attorneys and all those persons in active concern or participation with them;

C. For an Order that Antares account for the infringement, and pay monetary damages to Plaintiffs sufficient to compensate for the infringement;

D. For an Order enhancing damages up to treble damages under 35 U.S.C. § 284, for the deliberate and willful nature of Antares' infringement;

E. For an Order that Antares pay interest on the damages award in the form of both pre-judgment and post-judgment interest;

F. For an Order declaring that this case is exceptional within the meaning of 35 U.S.C. § 285, and ordering Antares to pay Plaintiffs' costs and expenses and its reasonable attorneys' fees under 35 U.S.C. § 285; and

G. For an Order granting Plaintiffs such other and further relief as the Court deems just and equitable.

DEMAND FOR JURY TRIAL

Pursuant to Rule 38 of the Federal Rules of Civil Procedure, the Plaintiffs hereby demand a jury trial on all issues triable of right by a jury.

Dated: August 11, 2005

Respectfully submitted,

By:____________________

Sarah Chapin Columbia (BBO# 550155)
Carlos Perez-Albuerne (BBO# 640446)
E. Page Wilkins (BBO# 654535)
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UNITED STATES DISTRICT COURT
DISTRICT OF MASSACHUSETTS

FURUKAWA ELECTRIC COMPANY OF NORTH AMERICA; OFS FITEL LLC,

Plaintiffs,

v.

YANGTZE OPTICAL FIBRE AND CABLE COMPANY LTD.,

Defendant.

Civil Action No. 05-cv-11219-RGS

DECLARATION OF CRAWFORD CUTTS

CRAWFORD CUTTS, first being duly sworn, deposes and says:

1. I am the President and sole shareholder of Antares Development International, LLC ("Antares"). I make this declaration on personal knowledge in connection with the Motion To Dismiss or, in the Alternative, To Stay Proceedings, to be filed in the above-captioned action by defendant Yangtze Optical Fibre and Cable Company Ltd. ("YOFC").

2. Antares is a Massachusetts limited liability corporation with a principal place of business in Sturbridge, Massachusetts.

3. On June 10, 2005, at Antares's place of business in Sturbridge, I was served with a summons and a copy of a complaint for the above-captioned action.

4. YOFC has no relationship to Antares ("Antares") other than a contractual one. YOFC owns no stake in Antares, and Antares owns no stake in YOFC.

5. I am not an employee or officer of YOFC. No other employee or officer of Antares is, or ever has been, an employee or officer of YOFC.

6. Attached as Exhibit A is a true and accurate copy of the contract between YOFC and Antares (the "Agreement"). I provide no services to YOFC beyond those called for by the Agreement. Antares provides no services to YOFC beyond those called for by the Agreement.

7. Both my and Antares's work for YOFC in Massachusetts has been limited merely to soliciting new customers for YOFC's optical fiber products. Thus, Antares has engaged in no activities in Massachusetts beyond those for which the Agreement calls.

8. Antares has always complied with the terms of the Agreement, has forwarded all requests for products to YOFC, and has never attempted to bind YOFC or to set prices, terms, or conditions for the sale of YOFC products.

9. Antares has never sold any YOFC product into Massachusetts. Nor has Antares ever attempted to place any orders with YOFC for Massachusetts customers. Thus, Antares has never provided customer support to purchasers of YOFC products in Massachusetts.

[Remainder of page intentionally left blank]

Signed under the pains and penalties of perjury on this 15th day of July, 2005.

/s/ Crawford Cutts

Crawford Cutts

EXHIBIT A

Antares Development International, LLC.

SALES REPRESENTATIVE AGREEMENT

This Agreement is made between Antares International Development, LLC (the "Representative") and YOFC (the "Company") ("collectively the parties"). This agreement becomes effective on January 15, 2004.

The parties agree as follows:

1. The Representative is appointed as the exclusive sales representative and shall use its best efforts to solicit, promote, and sell the Company's products as set forth in Schedule 1, Section A (the "Products") to the customers set forth in Schedule 1, Section B (the "Customers") within the geographical area set forth in Schedule 1, Section C (the "Territory"). Representative shall also perform such additional duties, if any, set forth in Schedule 1, Section D.

2. The Representative shall maintain its own office space and facilities and provide and maintain an adequately trained sales organization. The costs of these items are to be borne solely by the Representative. Other than the commission payments set forth in Appendix A and in paragraph 6 below, Representative shall not be entitled to payment for services provided or costs incurred as a result of this Agreement.

3. The Representative's major responsibilities should be as follows:

   (a) To generate and stimulate interest in the Products and furnish information to the Company in regard to market trends and prospective Customers for the Products.
   (b) To Act as a exclusive representative of the Company and promote and sell the Products in the Territory. The Representative will not represent or sell in any way the Products manufactured by any other companies in the Territory within the effective period of the Agreement. In the case that the Representative has been observed and found selling at the same time the Products from manufacturers other than the Company, this agreement will be terminated immediately without giving the written notice to the Representative.
   (c) To Participate in the sales promotion activities to benefit sales of the Products and assist and advises the Company in this regards.
   (d) To Cooperate with and assist the Company with the collection of any overdue accounts and other matters as requested by the Company.
   (e) To protect and promote the name, reputation and goodwill of the Company and its Products.
   (f) To provide the technical support and after-sales service to the Customers periodically.
   (g) Not to sell the Product to any Customer within the Territory if to the knowledge of the Representative that Customer intends to resell the Product in any country which is outside the Territory.

4. The Representative and the Company will cooperate to reach a sales target of no less than 2.5M USD in 2004 and no less than 5 M, 8M and 11M separately in the year 2005, 2006 and 2007. If such a sales target is not realized in a certain year, the two parties will review the situation and revise the target accordingly.

5. Representative shall summarize its sales activities and report to The Company quarterly to assist The Company in formulating its sales strategy in the Territory.

6. The Company shall pay the Representative commissions on all orders from Customers in the Territory for Products that have been shipped and invoiced as follows:

(a) Unless otherwise agreed by the parties, Commissions shall be paid on the "net sales price" (DDU) stated in the invoice or on a per kilometer basis according to the Commission Rate Schedule attached as Appendix A. "Net sales price" does not include any additional payments made by the Customer, including but not limited to tax, transportation, insurance, special tooling, or special packaging charges.

(b) A commission invoice from the representative shall be issued to The Company. The Commissions shall be paid via wire transfer within ten (10) days after the later of (i) the date the product is shipped from the Company's facilities and (ii) the date the company receives full payment from the customer.

(c) The Company may adjust commissions previously paid to the Representative as a result of goods returned for credit. If adjustments are made to the commissions previously paid, the Company may deduct such amounts directly from subsequent commission paid to the Representative. Otherwise, the Representative shall remit to the Company the amount of such adjustments within thirty (30) days of the date of notification by the Company of the adjustments. The Representative shall accept as final the Company's decision regarding such adjustments.

(d) In cases where a Customer operates branches outside the Territory and billing is made from a central location, the Company may choose to give sales credit based on location of Customers sales rather than billing location. In such cases, the Company shall have absolute discretion in determining the sales basis on which commissions are paid.

7 The Representative shall have no authority to bind the Company in any manner whatsoever. Products shall be sold upon the terms, prices and conditions set by the Company, which may be changed from time-to-time by the Company at its sole discretion. All orders and quotations shall be taken and given in the Company's name. The Company may reject or refuse, in whole or part, any orders or requests for quotations submitted by the Representative. The Company shall have no liability to the Representative for failure to fulfill any order and shall have the sole right to make any and all credit decisions.

8. The Representative acknowledges that it is not a franchisee or dealer within the meaning of any federal or state statute or regulation applicable in the Territory, and hereby waives any claims against the Company under any statute or regulation regarding franchise or dealership practices.

9. This Agreement will remain in force until November 15, 2007 and cannot be terminated for any reason prior to November 15, 2007 subject to the provisions of Article 3 (b) of this Agreement. After November 15, 2007, this agreement shall continue until terminated by either party, for any reason, upon thirty (30) days prior written notice to the other party. The Company shall pay the Representative all commissions that have accrued and are due and owing at the time of termination within thirty (30) days of termination of this Agreement as well as all commissions for sales up to the time of termination.

10. If this Agreement is terminated by either party for any reason, Representative shall be entitled only to the payment set forth in paragraph 6 above, and shall not be entitled to any additional payment, reimbursement or damages, including but not limited to those for: (1) loss of present or prospective sales, goodwill or the value of the business of the Representative; or (2) expenditures, investments, leases or commitments made by the Representative in connection with performance of this Agreement, even if such loss results from reliance on statements made to the Representative by the Company or any of its agents.

11. Representative shall not use or disclose any of the Company's "confidential information" during the term of this Agreement or for a period of two years thereafter. "Confidential information" shall include all non-public information regarding Company's customers, suppliers, and potential acquisition targets; their business operations and structures; their product line design or pricing; their processes, machines and inventions; their research and know-how; their financial data; and their plans and strategies. "Confidential information" does not include information that was known by Representative prior to disclosure; is or becomes available to the public in published literature from a source other than Representative before or during the term of this Agreement; is lawfully obtained by Representative from a third party or parties which did not require Representative to hold the Confidential information or any part thereof in confidence and which did not acquire the Confidential information or any part thereof, directly or indirectly, from the Company under an obligation of confidence; or is released in writing by the Company from the terms of this Agreement. Representative shall return to the Company, upon demand, all documents relating to such information and shall not retain copies of such returned documents. Representative shall return all material furnished to it by the Company, including, but not limited to price books, customers lists and catalogs. The materials shall be returned within thirty (30) business days of termination of this Agreement, or at any other time upon Company's request.

12. This Agreement shall be governed by and construed in all respects in accordance with the laws of the People's Republic of China excluding its choice of laws and rules. The Company represents and warrants to the Representative that this Agreement (a) has been duly authorized, executed and delivered by the Company, (b) is a legal, valid and binding agreement under the laws of the People's Republic of China, and (c) is enforceable in accordance with its terms.

13. Any disputes arising from the execution of or in connection with this Agreement shall be settled through friendly consultation between the parties, If the disputes are not resolved in this manner within sixty (60) days after the delivery by one party of a written notice confirming the existence of the disputes, then the disputes shall be submitted to China International Economic and Trade Arbitration Commission in Beijing for arbitration in accordance with the Commission's arbitration rules in effect at the time of applying for arbitration. The arbitral award is final and binding upon both parties. When any disputes occur and when any disputes are under arbitration, except for the matters under disputes, the parties shall continue to fulfill their respective obligations and shall be entitled to exercise their rights under this Agreement.

14. This Agreement constitutes the entire agreement of the parties concerning its subject matter and supersedes all other oral or written understandings, discussions, and agreements, and may be modified only in writing signed by both parties.

Antares Development International, LLC.

By: C. L. Cutts 1/18/2005.

Accepted this _18_ day of _January_, 2005

YOFC:

By: Yan Changkun

Title: Sales director

Date: Jan 18, 2005

SCHEDULE 1

__Section A:__ PRODUCTS

All YOFC multimode, single mode and specialty fiber and preforms, rods & tubes

__Section B:__ CUSTOMERS (excluding Draka Comteq USA)

1. Optical Cable Corporation

All customers in the territory other than Draka Comteq USA

__Section C:__ EXCLUSIVE TERRITORY

1. North America
2. Other countries that are mutually agreed upon by two parties in written form.

__Section D:__ ADDITIONAL DUTIES

None

APPENDIX A

COMMISSION SCHEDULE

COMMISSION RATE SCHEDULE

Multimode Fiber and Preforms

The commission rate for all shipments into the Territory in 2004 will be as follows:

1. For all multimode shipments to OCC, the commission rate will be $2.00 USD/km
2. For all multimode shipments to customers other than OCC, the commission rate will be 8% of the DDU price.

The commission rate for all shipments into the Territory after December 31, 2004 will be as follows:

1. For multimode fiber shipped to OCC, the commission rate will be 5% of the DDU price
2. For multimode fiber shipped to customers other than OCC, the commission rate will be 8% of the DDU price

Singlemode Fiber and Preforms

The commission rate for sales of all singlemode fiber will be $1.00 USD/km from the effective date of this agreement.

All commissions shall be paid via wire transfer within ten (10) days after the later of (i) the date the product is shipped from the Company's facilities or (ii) the date the company receives full payment from the customer.

Specialty Fiber and Preforms

The commission rate will be 10 % of the DDU price of the specialty fiber products.

Wire Transfer Instructions

All commissions payable to Representative under this agreement will be made via wire transfer to:

Account Name Holder: Antares Development International, Inc.
Sovereign Bank
70 East Main Street
Westborough, Mass. USA

Routing Number: 011075150
Account Number: 72200015401

and the Far East. Located in China's "Optical Valley" in Wuhan, YOFC operates the world's second largest optical fiber manufacturing facility using the patented and proprietary Plasma Chemical Vapor Deposition process. The PCVD process is widely recognized as the industry's most effective process for the precise manufacturing of complex index profile fibers such as high bandwidth multimode, dispersion controlled or low water peak single mode and other special designs

US Contact:

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Yangtze Optical Fibre and Cable Company, Ltd.

PRESS RELEASE **JANUARY 24, 2005**

YOFC Appoints Sales, Marketing and Technical Talent in North America

Wuhan, China, JANUARY 24, 2005- Yangtze Optical Fibre and Cable Company, Ltd. (YOFC) manufacturer and worldwide supplier of industry-leading optical fiber and cable, today announced the establishment of it's North American Sales, Marketing and Technical Operations Team: Mr. Crawford Cutts, formerly VP, Business Development at SpecTran Corporation and Director, Strategic Accounts at Juniper Networks; and Mr. Bill Beck, formerly President of SpecTran Specialty Optics and co-founder and CEO of Verrillon. YOFC appointed Cutts and Beck exclusive sales agents for North America.

"Bill and I are very pleased to be representing YOFC in North America for the sale of single mode, multimode fiber and specialty fiber designs", Cutts said. "The Plasma Chemical Vapor Deposition (PCVD) technology used by YOFC is widely recognized in the industry as the most effective process for the precise manufacturing of complex index profile optical fibers such as 10 GbEthernet 50 micron multimode, low water-peak single mode and new specialty designs. YOFC has been supplying this high quality fiber to customers in the US continuously for over 10 years."

"Crawford will focus on multimode and single mode fiber for traditional communications applications; I will focus on supporting customers requiring specialty designs", Beck said.

Yan Changkun, Sales Director of YOFC noted, "Crawford and Bill have many years of experience in this industry and can quickly establish a strong position for YOFC in the North American market. They have a comprehensive understanding of fiber optic technology and applications. Their strong relationships with the customer base make them a perfect fit for our customer-focused organization."

Cutts was Vice President of Business Development at SpecTran Corporation from 1990 to 1996. He assumed the position of President of General Photonics, a SpecTran and General Cable joint venture manufacturing optical cable, until SpecTran was sold to Lucent in 1999. From 2000 to 2003, Mr. Cutts was Director, Strategic Accounts at Juniper Networks.

Beck began his career in fiber optics in 1981. He was a pioneer in the development of specialty fiber applications as President of Ensign-Bickford Optics, SpecTran Specialty

Optics and most recently as co-founder and CEO of Verrillon. He has been consulting in fiber optics, sensors and lasers for the past two years and is Secretary of the New England Fiberoptics Council.

About YOFC

Yangtze Optical Fibre and Cable Company, Ltd. (YOFC) was established in 1988 by Philips of the Netherlands and China's Ministry of Post and Telecommunications. Today, YOFC is the largest supplier of optical fiber and cable to the Chinese market and exports its products to the United States and several countries in the Americas, Europe and the Far East. Located in China's "Optical Valley" in Wuhan, YOFC operates the world's second largest optical fiber manufacturing facility using the patented and proprietary Plasma Chemical Vapor Deposition process. The PCVD process is widely recognized as the industry's most effective process for the precise manufacturing of complex index profile fibers such as high bandwidth multimode, dispersion controlled or low water peak single mode and other special designs

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United States Patent [19]

Baumgart et al.

[11] Patent Number: 4,820,322

[45] Date of Patent: Apr. 11, 1989

[54] METHOD OF AND APPARATUS FOR OVERCLADDING A GLASS ROD

[75] Inventors: Jerry W. Baumgart, Norcross; Anthony T. D'Annessa, Marietta, both of Ga.; Franz T. Geyling, Morristown, N.J.; William M. Flegal, Tucker, Ga.; Thomas J. Miller, Belle Mead, N.J.

[73] Assignees: American Telephone and Telegraph Company AT&T Bell Laboratories, Murray Hill; AT&T Technologies, Inc., Berkeley Heights, both of N.J.

[21] Appl. No.: 99,441

[22] Filed: Sep. 23, 1987

Related U.S. Application Data

[63] Continuation of Ser. No. 856,739, Apr. 28, 1986, abandoned.

[51] Int. Cl.[4] C03B 37/025

[52] U.S. Cl. 65/3.11; 65/4.2; 65/13

[58] Field of Search 65/2, 3, 11, 3.12, 13, 65/4.2, 4.21

[56] References Cited

U.S. PATENT DOCUMENTS

3,455,667	7/1969	Snitzer et al.	65/4.2
4,123,483	10/1978	Nakaara et al.	
4,154,591	5/1979	French et al.	
4,184,859	1/1980	Maklad	
4,283,213	8/1981	Akers et al.	65/2 X
4,326,869	4/1982	Kurosaki et al.	65/3.11 X
4,505,729	8/1985	Matsumura et al.	65/3.11
4,551,162	11/1985	Hicks, Jr.	
4,569,589	6/1986	Perry	65/3.12
4,578,096	3/1986	Siegmund	65/3.11

FOREIGN PATENT DOCUMENTS

3521684	8/1984	Australia	
54-131043	of 0000	Japan	65/3.11
57-19064	of 0000	Japan	
53-133044	of 0000	Japan	65/3.11
2106892	of 0000	United Kingdom	
2148874	6/1985	United Kingdom	

OTHER PUBLICATIONS

Csencsits, et al., app. Ser. No. 447,417, Filed 12/2/82.

T. J. Miller and F. T. Geyling; "One Dimensional Models for the Co—Drawing of Preform Rods in Tubes", *Journal of Lightwave Technology*, vol. LT—2, No. 4, Aug. 1984.

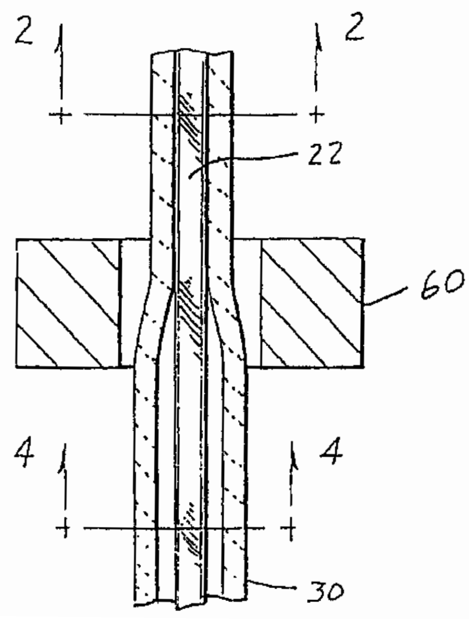
Primary Examiner—Robert L. Lindsay

Attorney, Agent, or Firm—Edward W. Somers

[57] ABSTRACT

Method and apparatus are provided for overcladding a preform rod (22). The preform rod is aligned with and inserted into an overcladding tube (30). The outer diameter of the preform rod and the inner diameter of the tube are such that the clearance between the tube and the rod does not exceed a predetermined value. Successive increments of length of the tube and rod therein are subjected to a controlled zone of heat while the pressure inside the tube is maintained at a value which is substantially less than that outside the tube. This causes the tube to be collapsed onto the preform rod to provide an overclad preform and subsequently a drawn optical fiber in which the overcladding is substantially concentric with respect to the optical fiber core.

23 Claims, 5 Drawing Sheets



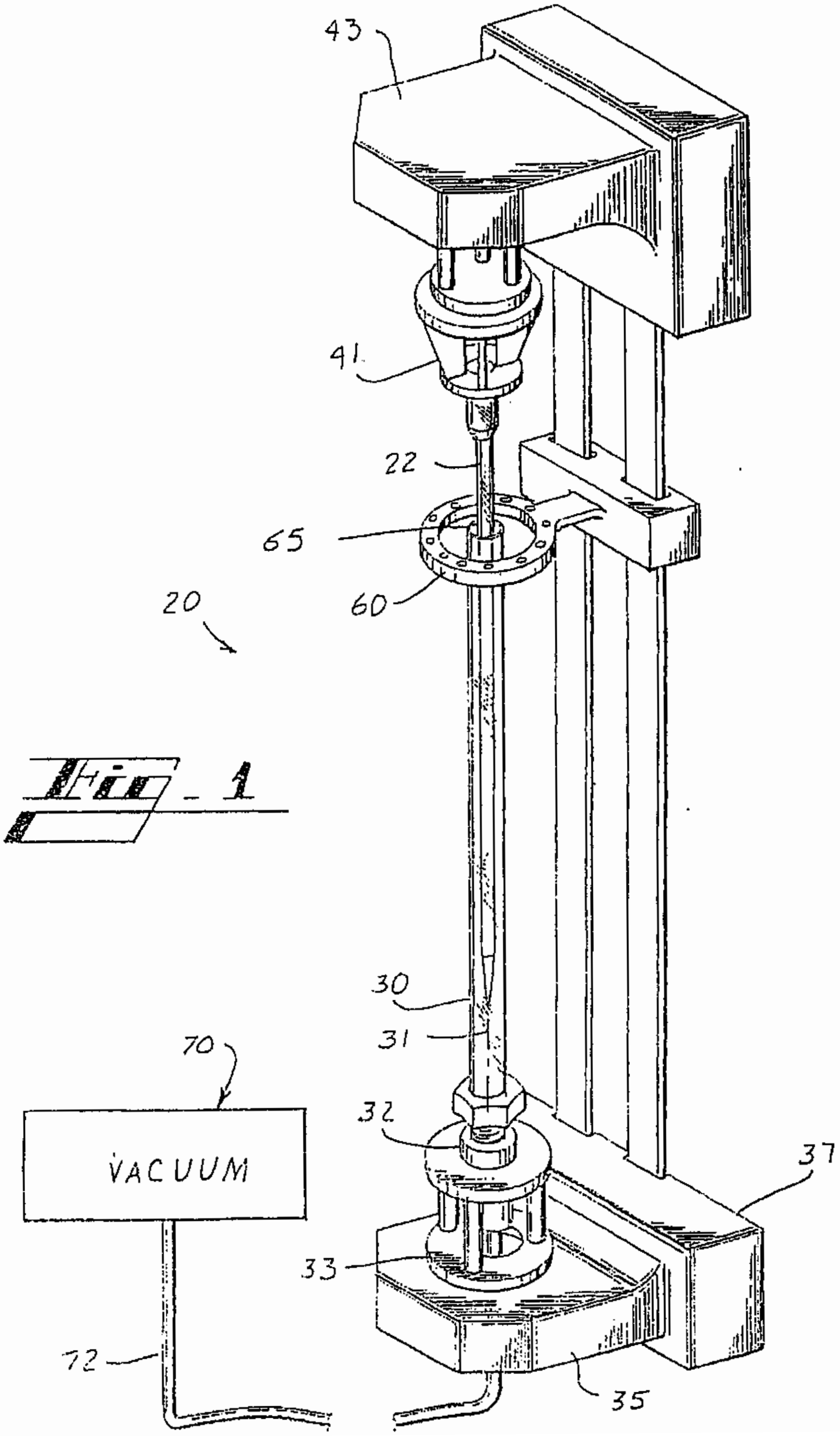


Fig. 1

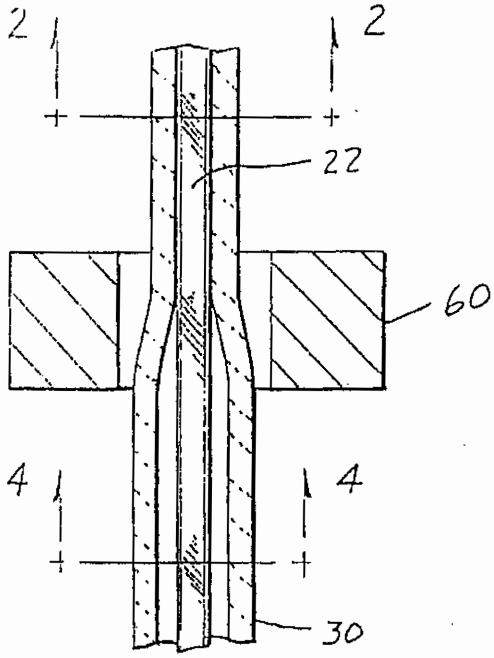


Fig_8

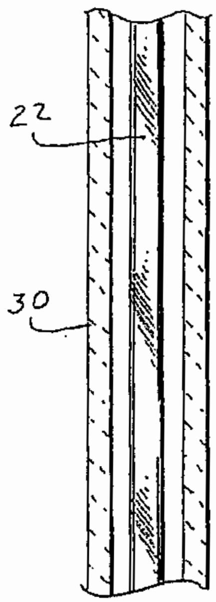


Fig_3

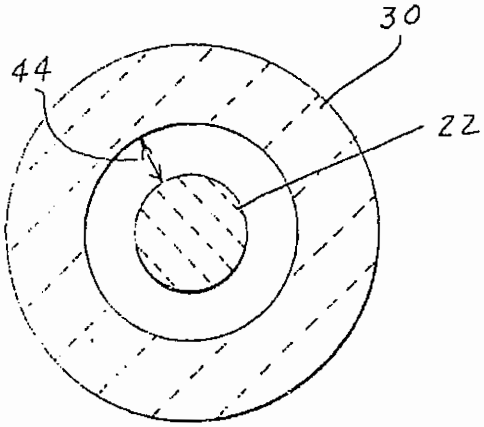


Fig_4

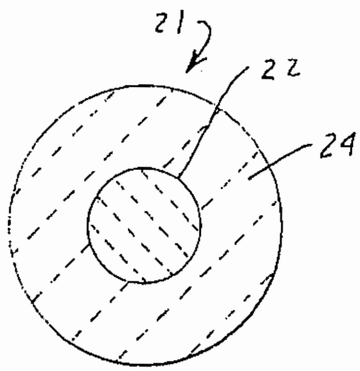


Fig_2

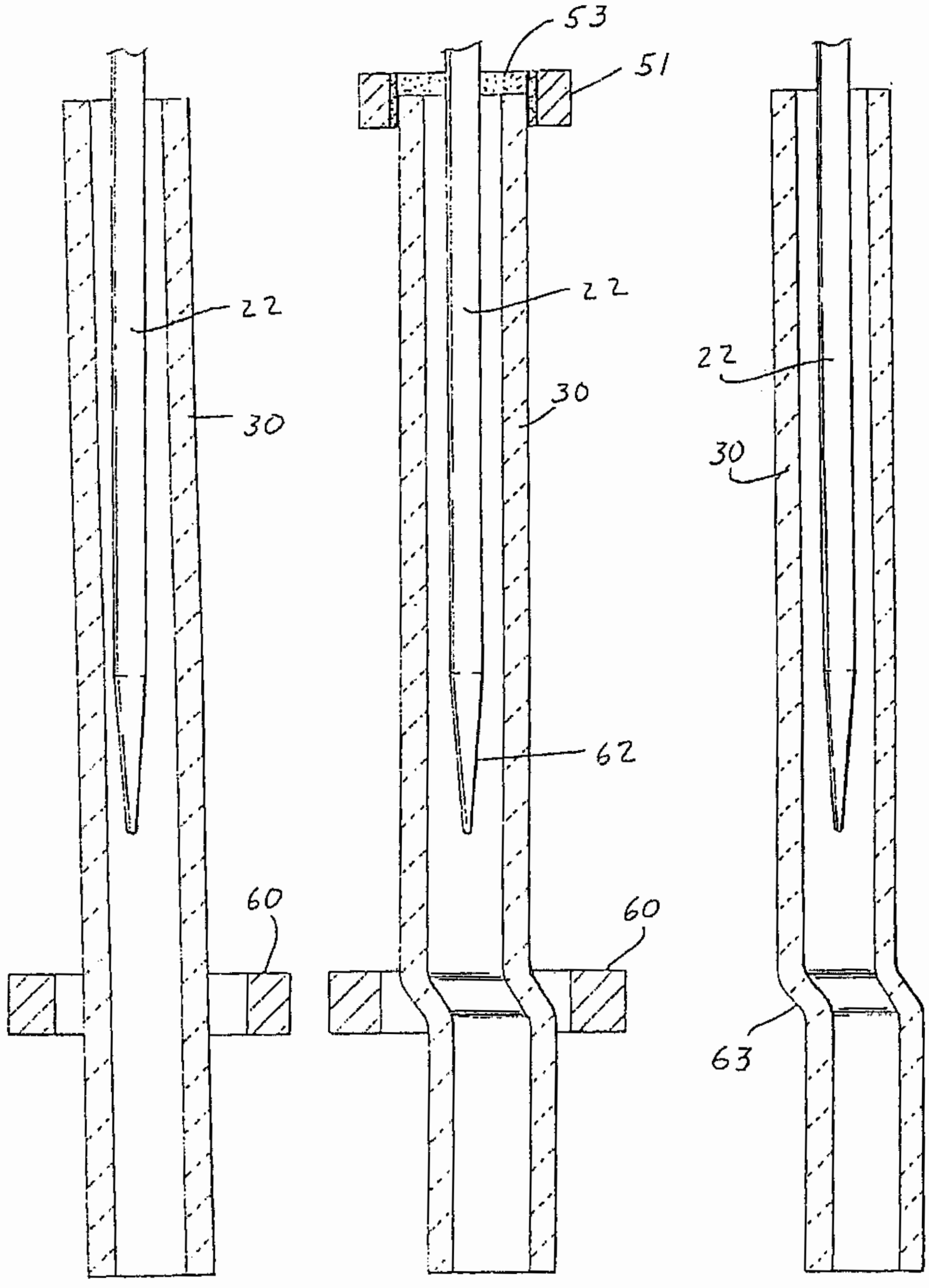


Fig_5 Fig_6 Fig_7

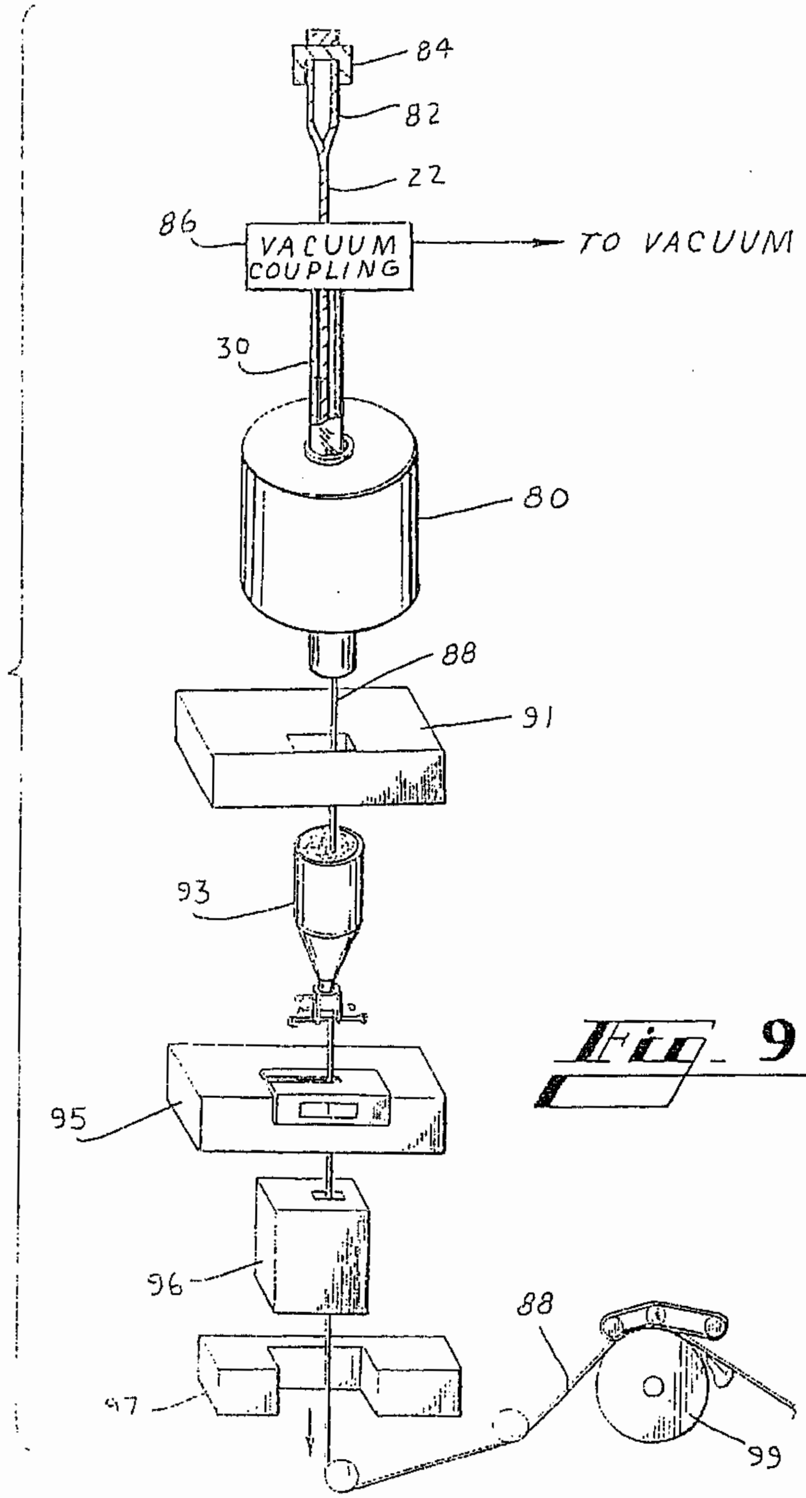

84
82
22
86
VACUUM COUPLING
TO VACUUM
30
80
88
91
93
95
96
88
97
99

FIG. 9

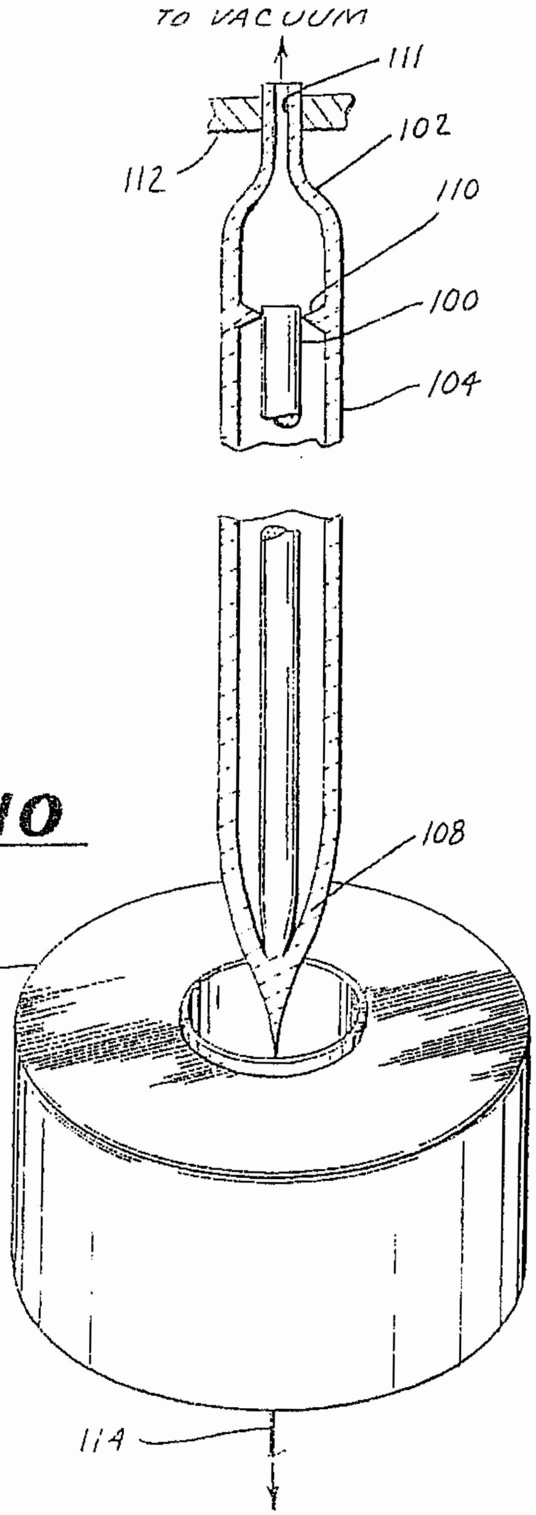


Fig. 10

METHOD OF AND APPARATUS FOR OVERCLADDING A GLASS ROD

This is a continuation of Application Ser. No. 856,739, filed Apr. 28, 1986, now abandoned.

TECHNICAL FIELD

This invention relates to methods of and apparatus for overcladding a glass rod. More particularly, this invention relates to methods and apparatus for causing a glass tube to be collapsed onto a glass rod to provide an optical fiber preform having a relatively thick wall.

BACKGROUND OF THE INVENTION

Optical fiber of the type used to carry optical signals is fabricated typically by heating and drawing a portion of an optical preform comprising a refractive core surrounded by a protective glass cladding. Presently, there are several known processes for fabricating preforms. The modified chemical vapor deposition (MCVD) process, which is described in U.S. Pat. No. 4,217,027 issued in the names of J. B. MacChesney et al. on Aug. 12, 1980 and assigned to Bell Laboratories, Inc., has been found most useful because the process enables large scale production of preforms which yield very low loss optical fiber.

During the fabrication of preforms by the MCVD process, precursor, reactant-containing gases, such as $SiCl_4$ and $GeCl_4$ are passed through a rotating substrate tube which is made of silica glass. A torch heats the tube from the outside as the precursor gases are passed therethrough, causing deposition of submicron-sized glass particles on the inside surface of the tube. The torch is moved along the longitudinal axis of the tube in a plurality of passes to build up layer upon layer of glass to provide a preform tube. Once a sufficient number of layers have been deposited, the preform tube is then heated to cause it to be collapsed to yield a preform or preform rod as it is often called.

Increased demand for optical fiber has prompted efforts to increase the productivity of the MCVD process. However, the MCVD process rate is limited by the thickness of the wall of the substrate tube. To obtain optical fiber having optimal optical and geometrical characteristics, the preform must have a core-to-cladding mass ratio within specified limits. Increasing the mass of the substrate tube to obtain a larger preform requires that the wall of the substrate tube be made thicker. Increasing the thickness of the wall of the substrate tube, however, reduces the rate of heat transfer to the reactant-containing gases, thereby increasing the time required to deposit each layer of glass particulates. If the wall of the substrate tube is too thick, then insufficient heat transfer may occur, which may result in the formation of bubbles or incomplete sintering.

One way in which the productivity of the MCVD process can be increased is first to produce an undercladded preform, having a larger than desired core-to-cladding mass ratio. This preform is inserted into a glass tube which is referred to as an overcladding tube and which is then collapsed onto the preform. This is referred to as the rod and tube technique. It is desirable that any added eccentricity of material about the preform core due to overcladding should be mimimized.

Insertion of the preform into the overcladding tube has been accomplished manually. Contact of the preform with the inside surface of the tube has not been found to be detrimental for present proof test levels of interest However, radial misalignment between the overcladding tube and the undercladded preform should be minimized, otherwise the resultant drawn fiber core may be too eccentric which inhibits proper splicing of the drawn fiber to another. More sophisticated methods and apparatus for inserting a glass rod into a glass tube are known.

Collapse of the tube onto the preform rod while the tube and rod are mounted in a horizontal lathe has been acomplished using an oxy-hydrogen torch such as one shown in U.S. Pat. No. 4,231,777 which issued on Nov. 4, 1980 in the names of B. Lynch and F. P. Partus. Because that torch has a relatively wide hot zone which does not have a sharply defined end, it has been found that air pockets become trapped between the tube and the preform rod during collapse and manifest themselves as air lines in the fiber, resulting in fiber breaks at low proof test levels. This problem may be overcome by gaseous cooling of the tube ahead of the torch, but this increases the hydrogen demand in the torch and may increase the likelihood of contaminating the tube surface. Voids also may occur at the interface between the preform rod and the tube because of non-concentric collapse of the tube on the rod.

Instead of being accomplished on a horizontal lathe, the collapse of the tube on a preform rod has been acomplished in a furnace. Typically, this has been accomplished by inserting the preform rod into an overcladding tube and then moving the rod and tube coaxially through a draw furnace which causes collapse prior to the drawing of the fiber. See U.S. Pat. No. 4,547,644, which issued on Oct. 15, 1985 in the names of W. C. Bair et al for a typical optical fiber drawing furnace. The fiber drawing process itself is relatively unaffected by tube collapse during drawing. However, the optical fiber draw rate may be reduced if the time required for collapsing the overcladding tube is the rate-limiting step of the fiber drawing process. Further, centering of the tube and inserted preform rod may be a problem in using the furnace to collapse the tube onto the preform rod. However, this may be overcome by a centering technique referenced to the optical fiber instead of to the preform rod.

Collapse of an overcladding tube onto a preform rod on a lathe subjects the preform to an extra heat treatment which is not required for furnace collapse. However, by accomplishing collapse on a lathe, the heat treatment step also acts to provide fire polishing of the overclad preform. The fire polishing step which is a surface treatment that removes defects causes the proof test yield of the drawn fiber to be increased.

U.S. Pat. No. 4,505,729 issued to H. Matsumura et al. on Mar. 19, 1985, discloses a method for producing an optical fiber preform the steps of which are a variation of the rod and tube technique discussed above. According to the Matsumura et al. method, a layer of doped glass particles is deposited on the inner surface of a quartz substrate tube. A glass rod is inserted into the substrate tube. The substrate tube, with the rod coaxially inserted therein, is then collapsed while the internal pressure of the tube is reduced slightly to provide a preform in which a cladding or jacket thereof is elliptic in cross section.

What is needed and what seemingly is not provided by the prior art are methods and apparatus for overcladding expeditiously a preform rod without degradation of fiber strength or core concentricity. The sought after

methods and apparatus that cause a glass tube, into which a glass preform rod has been inserted, to be collapsed onto the rod should result in a preform having substantially concentric layers with no air pockets at the interface between the rod and the tube. Desirably, such sought after methods and apparatus will increase the capacity of existing plant facilities. Inasmuch as increased fiber output can be more than offset by a decrease in the yield, care must be taken to insure that the sought after collapse process for rod and tube manufacture does not result in a decreased yield.

SUMMARY OF THE INVENTION

The foregoing problems have been solved by the methods and apparatus of this invention which provide an overclad preform. Initially, a preform rod and a tube which have predetermined optical and geometrical characteristics and which are substantially straight are provided. The preform rod is aligned with the tube after which relative motion is caused between them to cause a substantial portion of the rod to become disposed within the tube. The outer diameter of the preform rod and the inner diameter of the tube disposed thereabout are such that the difference therebetween does not exceed a predetermined value. Successive portions of length of the tube and the preform rod therein are subjected to a controlled zone of heat while a pressure gradient between the outside and the inside of the tube is established such that the pressure outside is substantially greater than that inside.

In a preferred embodiment, the pressure inside the tube is caused to be substantially less than ambient. In the preferred embodiment, the pressure inside the tube is about 0.15–0.2 atmosphere whereas outside, the ambient pressure is atmospheric.

BRIEF DESCRIPTION OF THE DRAWINGS

Other features of the present invention will be more readily understood from the following detailed description of specific embodiments thereof when read in conjunction with the accompanying drawings, in which:

FIG. 1 is a perspective view of an apparatus for causing a preform rod to be inserted into and aligned with a tube and for causing the tube to be collapsed onto the preform rod;

FIG. 2 is an end cross sectional view of an overclad preform which is provided by methods and apparatus of this invention;

FIG. 3 is an elevational view in section which shows a preform rod disposed in a tube with the difference between the diameter of the preform rod and the inner diameter of the tube being exaggerated for purposes of clarity;

FIG. 4 is an end sectional view of the rod and tube of FIG. 3;

FIGS. 5–7 are a sequence of views which depict the alignment of a preform rod within a tube;

FIG. 8 is an elevational view partially in section which shows a torch being moved along a tube within which is disposed a preform rod to cause the tube to become collapsed onto the preform rod;

FIG. 9 is another apparatus which may be used to cause a tube to be collapsed onto a preform rod, during the drawing of optical fiber, to overclad the rod; and

FIG. 10 is an alternate embodiment of an arrangement in which a tube is caused to be collapsed onto a preform rod during the drawing of optical fiber.

DETAILED DESCRIPTION

Referring now to FIG. 1, there is shown an apparatus, which is designated generally by the numeral 20 and which is used to provide a preform 21 (see FIG. 2) which comprises a preform rod 22 and an overcladding 24. The preform rod 22 is one which includes a core and cladding each having predetermined optical and geometrical characteristics. The preform rod 22 may be manufactured by the well-known process which is referred to as modified chemical vapor deposition (MCVD), for example. For a disclosure of the MCVD process, see priorly mentioned U.S. Pat. No. 4,217,027 which is incorporated by reference hereinto.

The preform rod 22 is to be provided with the overcladding 24 in order to improve production efficiency. This is accomplished by providing a tube 30 (see FIGS. 1 and 3–4) which is made of glass having predetermined optical and geometrical characteristics, by causing the preform rod 22 to become disposed within the tube 30 and by causing the tube to become collapsed onto the rod (see FIG. 2). In order to help to insure concentricity of the collapsed tube and the core of the preform rod 22, the tube and particularly the preform rod which is inserted into the tube 30 must be substantially straight.

As can be seen in FIG. 1, the tube 30 is caused to be mounted with a longitudinal axis 31 thereof extending vertically. Also, the tube 30 is mounted in a gimbal-type chuck 32 which is mounted in a holder 33 supported on a lower arm 35 of a vertical lathe frame 37, so that it is hinged and can be moved pivotally in any direction about its base. Advantageously, the lower chuck 32 also provides a seal with the outer surface of the tube 30. The preform rod 22 is suspended from an overhead chuck 41 and aligned with the tube. The chuck 41 is supported from an upper arm 43 which is cantilevered from the lathe frame 37. Afterwards, relative motion is caused between the lower and upper lathe arms 35 and 43, respectively, and hence between the tube and the preform rod to cause a substantial portion of the length of the preform rod to become disposed within the tube.

Steps are taken in order to maintain substantial concentricity of the tube 30 with respect to the preform rod 22. The preform rod 22 must be substantially straight. Also, a clearance 44 (see FIG. 4) at any point between the outer surface of the preform rod 22 and the inner surface of the tube 30 is controlled. This is accomplished by selecting the tube 30 and the preform rod 22 so that the difference between the inner diameter of the overcladding tube 30 and the outer diameter of the preform rod is such that the clearance is no greater than a predetermined value. For example, for a preform rod having an outer diameter of 17.5 mm and a tube having an inner diameter of 19 mm, that predetermined value is 1.5 mm. Of course, the rod should be disposed concentrically within the tube (see FIG. 4), providing a uniform clearance 44 desirably which is no greater than about 0.75 mm.

Although it is preferred that the preform rod 22 be centered within the tube 30 at the outset, this objective is not always achieved upon insertion and the rod sometimes touches the tube prior to collapse or is not concentric therewith (see FIG. 5). Should there be a precollapse touching or non-concentric condition, the resulting overclad preform will have a center which is offset from the center of the preform rod 22 provided by the MCVD process. The distance from the center of the core of the preform rod 22 to the center of the

assembly of the preform rod and the cladding tube 30 is termed the eccentricity.

Accordingly, in order to reduce the precollapse eccentricity of the preform rod 22 in the tube 30, the tube is caused to be provided with an offset. This movement is facilitated by the gimbal-type joint of the tube at its base which permits pivotal movement in any direction.

Prior to beginning the collapse mode, the position of the preform rod 22 is caused to be adjusted vertically with respect to the tube 30. Initially, an operator positions a centering collar 51 about an upper end of the tube 30 (see FIG. 6). Disposed within the centering collar 51 is an annulus 53 of a resilient material, for example. The resilient material engages the preform rod 22 and the tube 30 and causes the rod to be centered within the tube 30 at the location of the collar. Then a ring-type torch 60 having a construction similar to that of the torch shown in U.S. Pat. No. 4,477,244, which issued in the names of J. R. Nis and C D. Spainhour on Oct. 16, 1984 and which is incorporated by reference hereinto, is caused to dwell at a location about 10 cm below a free end 62 (see FIG. 6) of the preform rod. The torch 60, which may be an oxy-hydrogen torch, for example, circumscribes the entire periphery of the tube 30. Of course, a torch which circumscribes only part of the tube 30 could be used. As the tube 30 and the rod 22 are caused to turn rotatably about their longitudinal axes, the torch 60 heats the tube 30 sufficiently to allow the tube to reposition itself and form an offset 63 (see FIG. 7) at the location of the dwell of the torch, allowing the tube to become centered about the preform rod 22. In effect, the tube 30 is stress-relieved by heating it at a specific location and by allowing it to align itself with the preform rod 22.

The effect of the offset 63 is to cause a substantial portion of the preform rod 22 to be aligned substantially concentrically with the tube 30. The offset greatly reduces the likelihood of the engagement of the tip of the preform rod 22 with the wall of the tube 30.

After the offset 63 is formed, the centering device is remove after which the ring-type torch 60 is caused to be moved upwardly from the base of the tube 30 to a top end 65 (see FIG. 1). For a predetermined dwell time, the torch 60 remains at or near the top end 65 of the tube 30 to cause the tube to become sealed to the preform rod 22 at that point.

As the torch 60 begins its predetermined dwell time at or near the top end of the tube 30, apparatus 70 (see FIG. 1) having a portion 72 which extends through the arm 35 and holder 33 and which is connected to a lower end of the tube is controlled to cause the pressure within the tube to be substantially less than that outside the tube. As a result, the sealing of the top end portion of the tube 30 to the preform rod 22 is accomplished with a vacuum assist. In a preferred embodiment, the pressure inside the tube may be in the range of about 0.15 to 0.2 atmosphere, for example. Advantageously, the gimbal-type chuck 32 functions as a vacuum coupler and through its tight seal with the tube 30 allows the vacuum between the tube and the rod 22 to be maintained.

After the dwell time, the torch 60 is caused to be moved downwardly, traversing the length of the tube. The vacuum which is maintained as the torch 60 traverses the length of the tube 30, subjecting successive increments of length of the tube to a zone of heat, causes the tube 30 to be collapsed at a relatively rapid rate onto the preform rod 22 (see FIG 8) to provide the overclad preform of FIG. 2. The zone of heat is controlled to avoid excessively high temperatures. By using lower temperatures, an axial temperature gradient is established over an increment of length of the tube. This allows the tube 30 to be maintained in alignment about the preform rod 22 because of the stiffness of the tube across the zone of heat.

As the torch 60 traverses the length of the tube 30, the tube and preform rod 22 are caused to rotate. This is done because the heating of the tube 30 and the rod 22 generally is not symmetrical. Also, the tube 30 and the preform rod 22 therewithin may not be precisely centered within the confines of the torch 60. It has been found that the resulting rod and tube product improves with slower rotational speeds. As the speed is increased, centrifugal effects increase and adversely affect eccentricity. In a preferred embodiment, the rotational velocity is about 10 rpm.

It should be noted that in the preferred embodiment of this invention, the pressure inside the tube 30 is reduced over that external thereto. In the preferred embodiment, this is done by connecting the tube 30 through the vacuum coupler chuck 32 to the source 70 of vacuum. However, the pressure outside the tube 30 could be increased to be substantially greater than that inside the tube to achieve the same result. What is important is that there be a substantial pressure gradient between the outside of the tube 30 and the inside with the pressure on the outside being substantially greater than that inside.

The methods and apparatus of this invention result in a substantially increased rate of collapse of the tube 30 onto the preform rod 22. With the methods and apparatus of this invention, collapse rates of about 7 cm/min have been achieved. This compares to a collapse rate of about 1 cm/min in a horizontal lathe arrangement without a pressure gradient other than that used in preform manufacture by the MCVD process. As is well known, in that process, preform tube collapse is accomplished while the pressure inside the tube is slightly greater than atmospheric.

The above-described pressure gradient is helpful in accelerating the rate of collapse of the tube on the rod; however, additional steps are taken to avoid ellipticities in the final preform and to cause the overcladding of the final preform to be concentric with the core of the preform rod. The additional steps include controlling the clearance between the tube and the rod, controlling the zone of heat, and controlling the initial concentricity between the tube 30 and the inserted rod. By controlling the width of the zone of heat and the temperature therein, as well as the characteristics of the gradient, and by controlling the clearance between the tube 30 and the preform rod 22, and the initial concentricity, vacuum assist may be used to accelerate tube collapse without any resulting ellipticities in the final preform.

Contrary to what might be expected from the disclosures of the prior art, the quality of the resulting overclad preform rod is relatively high when using the methods and apparatus of this invention. From the prior art, it appears that positive pressure during collapse is needed, but that the use of vacuum results in ellipticity of portions of the preform. For example, it is known that in order to make a polarized optical fiber, an optical preform tube is fabricated and then collapsed under conditions wherein a vacuum within the tube is maintained. The vacuum causes ellipticities in the tube to be increased so that the fiber upon collapse is in a more elliptical state than was the tube at the beginning of the

collapse process. A non-zero ellipticity typically is produced by including a vacuum within the tube during an initial portion of the collapse. An internal pressure is then applied during collapse that increases as the radius of the tube decreases, so as to maintain the given degree of ellipticity during further collapse of the tube.

It has been found that it is relatively simple to flatten a tube when the rod therein is relatively small compared to the tube. The prior art relies on this principle to achieve ellipticities in the final configuration of an overclad tube. However, with rod sizes which approach the inner diameter of the tube, the tube does not have sufficient room to flatten. In the methods and apparatus of the present invention, the clearance between the inner wall of the tube 30 and the outer surface of the preform rod 22 is controlled and is sufficiently small so that ellipticity is minimized.

Further, according to the prior art, circularity may be preserved during collapse with the aid of positive internal pressure. See U.S. Pat. No. 4,154,591 which issued on May 15, 1979 in the names of W. G. French and W. Tasker. However, it has been found that the use of pressure slightly greater than atmospheric such as during preform collapse in the MCVD process has not provided acceptable results for providing an overclad tube. Collapse with the positive pressure technique of the MCVD process has been found to be non-symmetrical, resulting in the formation of air voids. In contrast, it has been found that voids do not occur at the interface of the preform rod and tube when using methods and apparatus of this invention.

As should be evident, care has been taken to minimize eccentricity of the final preform product. If done on a lathe, albeit vertical, most of the heat is provided to the tube 30 and hence only the tube is deformed. If the tube 30 is off center, it may touch the rod at one point first and the material adhering to the rod is immobilized. The tube wall thickness at the point where the sticking first occurs is frozen. The remainder of the tube 30 continues to collapse. and, as it does, the wall thickness of the tube increases. Hence, the portion of the overclad preform where the tube is last to touch the preform rod has the greatest wall thickness, and the part that first touches the preform rod has its least wall thickness. These two locations are generally diametrically opposite to each other, resulting, undesirably, in eccentricity.

Unlike some prior art techniques where evacuation has been used to obtain elliptical shapes in the final rod and tube cross section, the methods and apparatus of this invention cause relatively rapid tube collapse while maintaining substantial concentricity of the rod and the tube. For example, it has been found that the eccentricity of fiber drawn from overclad preform rods produced in accordance with the methods and apparatus of this invention is less than one micron.

The zone of heat is controlled to cause the temperature gradient to be relatively steep. As is well known, the zone of heat is the zone extending from the location where the temperature reaches about 1600° C., which is the softening point of the glass used herein, to the location where it drops below that temperature. For the torch which is used in the vertical lathe arrangement of FIG. 1, the distance over which the temperature increases from 1600° C. to its maximum value is relatively small and typically is about 10 mm. Problems are avoided by controlling the zone of heat so that it is relatively narrow and relatively steep.

Furthermore, the zone of heat is controlled so that as a result of collapse, substantially all the inner surface of the tube 30 is in engagement with the preform rod. This helps to avoid the formation of voids between the tube and the rod which may result in degradation of the optical fiber strength. Also, the collapsed tube is concentric with respect to the rod because of the initial alignment precautions taken and because the width of the hot zone is not so great that it causes instabilities.

Other variations of the arrangement which is shown in FIG. 1 may be used. For example, it has been demonstrated that the rod 22 instead of the tube 30 may be mounted in the chuck 32, and the tube 30, instead of the rod, mounted in the overhead chuck 41.

The methods and apparatus of this invention also are applicable to the collapsing of the tube 30 onto the preform rod 22 as the preform rod and tube are advanced into a draw furnace 80 (See FIG. 9). In the vertical lathe arrangement, the tube 30 is heated and the heat energy re-radiated into the rod. In the draw furnace, heat energy is provided directly into both the tube 30 and the preform rod 22. Furthermore, the maximum zone of heat temperature in the furnace is greater than that in the lathe. Thus, both the preform rod 22 and the tube 30 experience a greater temperature resulting in a lower vicosity and greater fluidity during the furnace collapse of tube 30 onto preform rod 22 when compared to the aforementioned lathe collapse technique. However, an axisymmetric draw force acts on both the preform rod 22 and tube 30 during co-drawing. The combination of greater fluidity and axisymmetric draw force acting on the preform rod 22 and the tube 30 in the co-drawing technique for overcladding provide a self-centering mechanism for the rod and tube assembly which tends to oppose the eccentricity of preform rod 22 in the tube 30 as described earlier.

As can be seen in FIG. 9, the preform rod 22 which is provided with a handle 82 is suspended from a chuck 84. The entrance of the preform rod 22 into the tube 30 is provided with a vacuum coupling 86 to seal the entrance and allow the volume between the inner wall of the tube and the outer surface of the rod to be maintained at a predetermined pressure. The preform rod 22 and the tube 30 extend into the furnace 80, which may be a zirconia induction furnace, for example.

As the preform rod 22 and the tube 30 are fed into the furnace, a source of vacuum (not shown) in a preferred embodiment is connected through the vacuum coupling 86 to the space between the tube and the preform rod. Successive portions of the length of the tube 30 within the furnace 80 are caused to be collapsed onto the preform rod 22 and an optical fiber 88 is drawn from the overclad preform. In the draw-down portion of the furnace, where the tube 30 and the rod 22 become fluid at the same time, the draw force from the fiber is thought to provide a self-centering mechanism for the tube and the rod. Alignment is aided by an axially symmetric drawing tension on both the preform rod 22 and the tube 30.

The diameter of the drawn optical fiber 88 is measured by a device 91 at a point shortly after it exits from the furnace and this measured value becomes an input to a control system. Within the control system, the measured diameter is compared to the desired value and an output signal is generated to adjust the draw speed such that the optical fiber diameter approaches the desired value.

After the diameter of the optical fiber 88 is measured, a protective coating is applied to it by an apparatus 93. Then, after the coated fiber 88 passes through a centering gauge 95, a device 96 for treating the coating and a device 97 for measuring the outer diameter of the coated fiber, it is moved through a capstan 99 and is spooled for testing and storage prior to subsequent cable operations. The preservation of the intrinsically high strength of optical fibers is important during the ribboning, jacketing, connectorization and cabling of the fibers and in their service lifetime.

When using a draw furnace to collapse the tube 30, the viscosity of the glass is lower because the temperature is higher. This allows flow of the glass but the axisymmetric draw force facilitates a concentric draw of the preform rod 22 and the tube 30 collapsed thereabout. In the furnace, typically, the ascent to the maximum temperature is more steep than when using the ring torch, but the traverse of the rod through the zone of heat may be slower than in the lathe arrangement. Inasmuch as the tube collapse is time-temperature dependent and inasmuch as the temperature of the furnace is somewhat fixed, control of the zone of heat is achieved by controlling its length along the tube 30. The temperature gradient is relatively step in the area where the tube collapses onto the rod.

In FIG. 10, there is shown an alternate embodiment of an arrangement in which a tube is collapsed onto a preform rod during the drawing of optical fiber. A preform rod 100 is provided by an MCVD process, for example. A tube 104 which has an inner diameter only slightly greater than the outer diameter of the preform rod and which has a handle 102 is caused to be disposed about the preform rod. The tube 104 is caused to be sealed to the rod at an end 108. Subsequently, another portion of the tube is tacked to the rod at a plurality of locations 110—110 about the peiphery of the inner surface of the tube. An opening 111 through the handle end 102 and connection through a supporting chuck 112 to a source of vacuum, for example, is provided to allow control of the pressure within the tube during the drawing of fiber. This arrangement maximizes the use of the relatively expensive preform inasmuch as none of it is used in supporting the rod and tube from the overhead chuck.

The handle 102 of the tube is supported to cause the preform rod with the tube sealed thereto to be suspended above a furnace 113. Then, as in the embodiment shown in FIG. 9, the preform rod and the tube are advanced into the furance to facilitate the drawing of an optical fiber 114 therefrom. As the length of the tube 104 decreases, the pressure within the tube is adjusted to maintain the gradient between it and that outside the tube within a controlled range.

A relatively low eccentricity overclad preform has been produced by optimizing the heat zone temperature and width which control the glass viscosity, the magnitude of the clearance between the preform rod and the overcladding tube and the pressure therein, and the concentricity of the preform rod inside the overcladding tube. All these parameters influence the process speed and resultant fiber geometry whereas the fiber strength is affected by the characteristics of the heat zone. The optimization of these parameters has resulted in a rapid overcladding process that provides optical fiber exhibiting strength and core concentricity which meet the specifications required in current commercial optical fiber systems. The overcladding process described herein significantly increases production capacity while substantially avoiding decreased fiber yield.

It is to be understood that the above-described arrangements are simply illustrative of the invention. Other arrangements may be devised by those skilled in the art which will embody the principles of the invention and fall within the spirit and scope thereof.

What is claimed is:

1. A method of providing an overclad optical preform in which an overcladding is disposed substantially concentrically about a core of an optical preform rod, said method including the steps of:

providing a substantially straight optical preform rod which includes a core and a cladding which has an outer diameter and a longitudinal axis;

providing an overcladding tube which is made of an optical material having suitable optical and geometrical characteristics and which has an inner diameter with the difference between the inner diameter of the tube and the outer diameter of the rod being relatively small, said overcladding tube having a longitudinal axis;

causing the preform rod to become disposed within the tube and then holding the preform rod at one end and the tube at an opposite end in positions fixed relative to each other in directions along the longitudinal axes thereof; and

subjecting successive increments of length of the tube with the rod disposed therein to a relatively narrow zone of heat having a controlled temperature gradient; while

causing a pressure gradient between the outside and the inside of the tube to be established and to be maintained with the pressure outside being substantially greater than that inside, the pressure gradient in cooperation with the relatively narrow zone of heat and the relatively small difference between the inner diameter of the tube and the outer diameter of the rod being effective to cause the tube to collapse substantially into engagement with the preform rod and with the overcladding tube being disposed substantially concentrically about the core of the preform rod, the difference between the inner diameter of the tube and the outer diameter of the rod being sufficiently small to prevent substantially any buckling of the tube as the tube is caused to collapse onto the rod.

2. A method of providing an overclad optical preform in which an overcladding is disposed substantially concentrically about an optical preform rod, said method including the steps of:

providing a substantially straight optical preform rod which has an outer diameter and a longitudinal axis;

providing an overcladding tube which is made of an optical material having suitable optical and geometrical characteristics and which has an inner diameter with the difference between the inner diameter of the tube and the outer diameter of the rod being relatively small, said overcladding tube having a longitudinal axis;

causing the preform rod to become disposed within the tube and then supporting individually the preform rod and the tube in positions substantially fixed relative to each other in directions along the longitudinal axes thereof; and

subjecting successive increments of length of the tube with the rod disposed therein to a relatively nar-

row zone of heat having a controlled temperature gradient; while

causing a pressure gradient between the outside and the inside of the tube to be esttablished and to be maintained with the pressure outside being substantially greater than that inside, the cooperation of the pressure gradient with said relatively narrow zone of heat and said relatively small difference between the outer diameter of the rod and the inner diameter of said tube being effective to collapse the tube substantially into engagement with the preform rod and with the overcladding tube being disposed substantially concentrically about the preform rod, with the difference between the inner diameter of the tube and the ouer diameter of the rod being sufficiently small to prevent substantially any buckling of the tube as the tube is caused to collapse onto the rod.

3. The method of claim 1, wherein prior to successive increments of the length of the tube being subjected to the zone of heat, an open end portion of the tube is caused to become sealed to the preform rod which extends into the tube, and wherein the pressure gradient is established by connecting the tube to a source of vacuum prior to the end portion of the tube being caused to become sealed to the preform rod.

4. The method of claim 3, wherein the pressure within the tube is in the range of about 0.15 to 0.2 atmosphere.

5. The method of claim 1, wherein the pressure gradient is caused by inceasing the pressure outside the tube.

6. The method of claim 23, wherein the preform rod is caused to be disposed substantially concentrically within the tube and the clearance between the tube and the preform rod does not exceed about 0.75 mm.

7. The method of claim 23, wherein the clearance between the tube and the preform rod does not exceed a value of about 1.5 mm.

8. The method of claim 23, wherein the temperature within the zone of heat is in the range of about 1600°-2200° C.

9. The method of claim 23, wherein said step of subjecting is carried out so that the zone of heat has a relatively steep temperature gradient.

10. The method of claim 23, wherein subsequent to the disposition of the preform rod in the tube, the portion of the preform rod adjacent to its entrance into the tube is caused to become disposed substantially concentrically with respect to said tube.

11. The method of claim 10, wherein the tube is subjected to heat energy for a predetermined time at a location adjacent to an end of the preform rod therein to allow the position of the tube between an entrance of the tube and a free end of the preform rod to be adjusted and to become substantially coaxial with the tube.

12. The method of claim 1, wherein the heat is applied to successive portions of length of the tube and preform rod therein in a furnace into which the rod and tube are advanced and from which an optical fiber is drawn from the rod and tube collapsed thereabout.

13. The method of claim 12, wherein prior to the insertion of the rod and the tube into the furnace, the rod is inserted into the tube and sealed to the tube at one end and connected in a plurality of locations at its other end to the tube.

14. The method of claim 1, wherein the preform rod and the tube are supported so that their longitudinal axes are substantially vertical.

15. An apparatus for overcladding an optical preform rod, said apparatus including:

first supporting means for holding a preform rod which is substantially straight along a longitudinal axis thereof so that the preform rod may be turned rotatably about its longitudinal axis;

second supporting means for holding a tube which is made of an optical material having predetermined characteristics and which has a longitudinal axis so that the tube may be turned rotatably about its longitudinal axis, said first and second supporting means allowing the preform rod to be held with a substantial portion of its length disposed in the tube, the tube having an inner diameter that is greater than an outer diameter of the rod to provide a relatively small clearance therebetween;

means for causing the preform rod and the tube to be turned rotatably each about its longitudinal axis;

heating means for causing successive increments of length of the tube with the rod therein to be subjected to a relatively narrow zone of heat while the tube and the rod are being turned rotatably; and

means rendered effective by said heating means causing successive increments of length of the tube and rod therein to be subjected to a relatively narrow zone of heat for establishing and for maintaining a pressure gradient between the inside and outside of the tube such that the pressure outside the tube is substantially greater than that inside, the cooperation of said pressure gradient, said relatively narrow zone of heat and said relatively small clearance between the tube an the rod being effective to cause said tube to be collapsed onto the rod, said clearance between the tube and the rod being sufficiently small to prevent any significant buckling of the tube as it is collapsed onto the rod.

16. The apparatus of claim 19, wherein said means for establishing a pressure gradient causes a vacuum to be applied to the tube.

17. The apparatus of claim 19, wherein said heating means includes a torch and said apparatus includes means for causing relative motion between the tube and said torch.

18. The method of claim 2, wherein the preform rod and the overcladding tube are caused to be turned rotatably each about its longitudinal axis as successive increments of length of the tube with the rod disposed therein are subjected to the zone of heat.

19. The apparatus of claim 15, which also includes means adapted to be disposed about the tube at the location where the rod extends into the tube and for causing the rod and the tube to be disposed concentrically with respect to each other at that location.

20. The apparatus of claim 19, wherein said first and second supporting means support the preform rod and tube so that their longitudinal axes are substantially vertical.

21. The apparatus of claim 20, wherein said second supporting means allows the tube to be moved pivotally about a lower end thereof.

22. A method of making an optical fiber, said method including steps of:

providing a substantially straight optical preform rod which has an outer diameter and a longitudinal axis;

providing an overcladding tube which is made of an optical material having suitable optical and geometrical characteristics and which has an inner

diameter with the difference between the inner diameter of the tube and the outer diameter of the rod being relatively small, said overcladding tube having a longitudinal axis;

causing the preform rod to become disposed within the tube and then supporting individually the preform rod and the tube in positions substantially fixed relative to each other in directions along the longitudinal axes thereof;

subjecting successive increments of length of the tube with the rod disposed therein to a relatively narrow zone of heat having a controlled temperature gradient; while

causing a pressure gradient between the outside and the inside of the tube to be established and to be maintained with the pressure outside being substantially greater than that inside and to cooperate with said relatively narrow zone of heat and the relatively small difference between the outer diameter of the rod and the inner diameter of the tube to cause the tube to be collapsed into engagement with the preform rod to provide an overclad preform in which the overcladding tube is disposed substantially concentircally about the preform rod, the difference between the inner diameter of the tube and the outer diameter of the rod being sufficiently small to prevent substantially buckling of the tube as the tube is caused to collapse onto the rod; and

drawing optical fiber from the overclad optical preform.

23. The method of claim 22, wherein the preform rod and the overcladding tube are caused to be turned rotatably each about its longitudinal axis as successive increments of length of the tube with the rod disposed therein are subjected to the zone of heat.

* * * * *

United States Patent [19]
MacChesney et al.

[11] **Patent Number:** 4,909,816
[45] **Date of Patent:** Mar. 20, 1990

[54] **OPTICAL FIBER FABRICATION AND RESULTING PRODUCT**

[75] Inventors: **John B. MacChesney**, Lebanon; **Paul B. O'Connor**, Plainfield, both of N.J.

[73] Assignee: **American Telephone and Telegraph Company, AT&T Bell Laboratories**, Murray Hill, N.J.

[21] Appl. No.: **517,430**

[22] Filed: **Jul. 26, 1983**

Related U.S. Application Data

[63] Continuation of Ser. No. 382,401, May 26, 1982, abandoned, which is a continuation of Ser. No. 147,934, May 8, 1980, abandoned, which is a continuation of Ser. No. 828,617, Aug. 29, 1977, Pat. No. 4,217,027, which is a continuation of Ser. No. 444,705, Feb. 22, 1974, abandoned.

[51] Int. Cl.[4] **C03B 37/025**; C03B 37/075

[52] U.S. Cl. **65/3.12**; 65/3.11; 65/3.2; 65/18.2; 350/96.30; 427/163; 427/167

[58] Field of Search 350/96.30, 96.31; 65/3.12, 3.11, 3.2, 18.2, 110; 427/163, 167, 231, 237; 264/1.2, 1.5

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,711,262	1/1973	Keck et al.	65/3.12
3,737,292	6/1973	Keck et al.	65/3.12
3,778,132	12/1973	Pinnow et al.	350/96
3,806,224	4/1974	MacChesney et al.	350/96
3,823,995	7/1974	Carpenter	65/3.12
3,853,384	12/1974	Pinnow et al.	350/96
3,884,550	5/1975	Maurer et al.	65/3.11 X
3,961,926	6/1976	Asam	65/3.12
3,963,468	6/1976	Jaeger et al.	65/3
4,341,441	7/1982	Lighty et al.	65/3.12 X

OTHER PUBLICATIONS

Powell et al., Vapor Deposition Textbook, pp. xii and 262–263, published by John Wiley & Sons, Inc., N.Y., 1966.
Journal of Electronic Materials, vol. 2, 1973; Editorial Page, Cover Pages for vol. 2, No. 1, and vol. 2, No. 2; pp. 159, 373, 617, 623; and Instructions to Contributors Page.
Hass et al.; Physics of Thin Films, pp. 238, 286–289, Academic Press, 1969.
Powell et al., "Vapor Deposition Textbook", pp. 11, 12; 149–153; 259–261; 391–397; 549–578, published by John Wiley & Sons, 1966.
French et al., Abstract F2, Conference Program–Preparation and Properties of Electronic Materials, Sponsored by Electronic Materials Committee of The Metallurgical Society of AIME, 1973.
Scientific and Industrial Glass Blowing and Laboratory Techniques, W. E. Barr et al., Jan. 1949, pp. 29–54 (Chapter II).
Scientific Glassblowing, E. L. Wheeler, pp. 64–65, Interscience Publishers, Inc., 1958.
75th Annual Meeting and Exposition, American Ceramic Society Bulletin, Abstract #29–G–73, A. D. Pearson, Apr. 1973, vol. 52, No. 4.
Proceedings of the 1973 *Electronic Materials Conference*, Aug. 29, 1973, Session F, Abstract #F2, W. G. French et al., p. 623, appearing in *Journal of Electronic Materials*, vol. 2, No. 4, 1973, p. 617.
Scientific and Industrial Glass Blowing and Laboratory Techniques, W. E. Barr et al., Jan. 1949, pp. ii–iii and 29.
Thin Film Technology, R. W. Berry et al., 1968, pp. 266–267.
Applied Physics Letters, vol. 23, #6, 1973, pp. 338–339.

Primary Examiner—Kenneth M. Schor
Attorney, Agent, or Firm—Bruce S. Schneider

[57] **ABSTRACT**

A preform for fabrication of a glass fiber optical transmission line is prepared by chemical reaction of vapor ingredients within a glass tube. Reaction, which may be between chlorides or hydrides of, for example, silicon and germanium with oxygen, occurs preferentially within a constantly traversing hot zone. Flow rates and temperature are sufficient to result in glass formation in the form of particulate matter on the inner surface of the tube. The particulate matter deposits on the tube and is fused with each passage of the hot zone. Continuous rotation of the tube during processing permits attainment of higher temperatures within the heated zone without distortion of the tube.

17 Claims, 2 Drawing Sheets

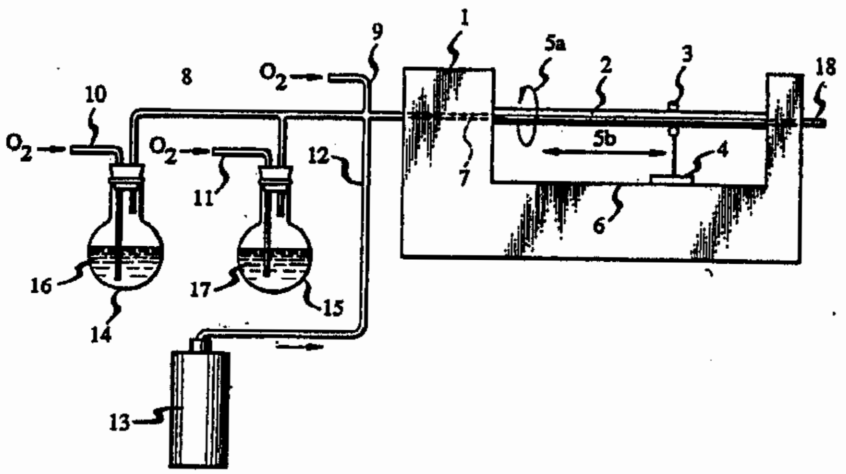


FIG. 1

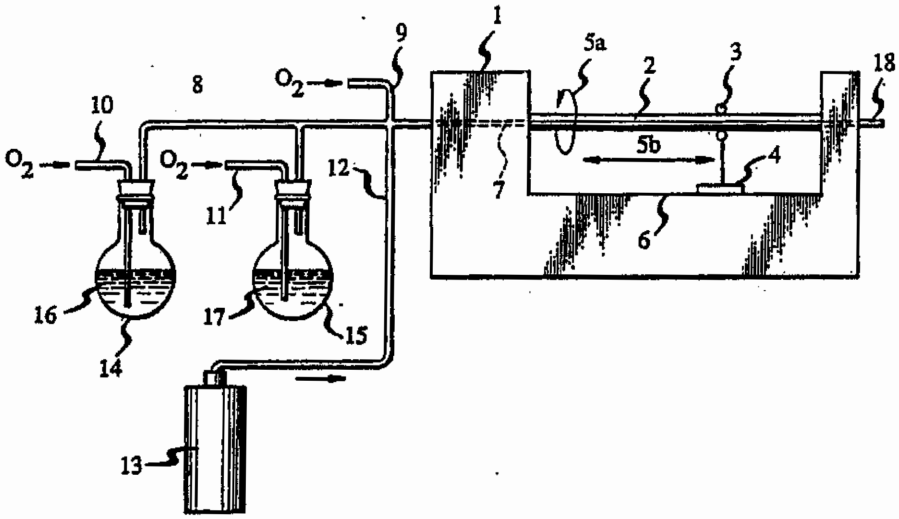


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FIG. 2

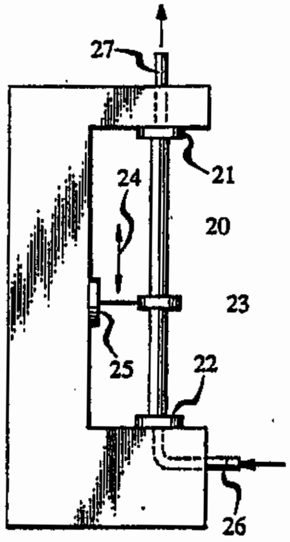

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FIG. 3

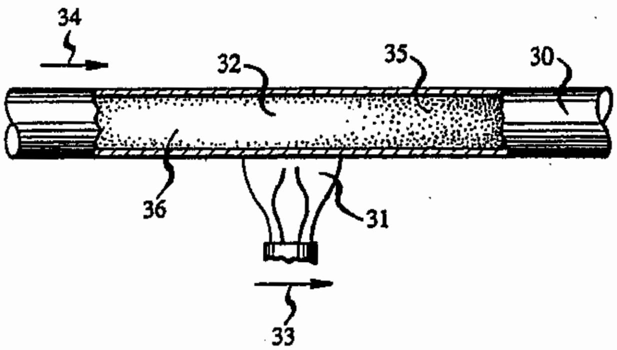
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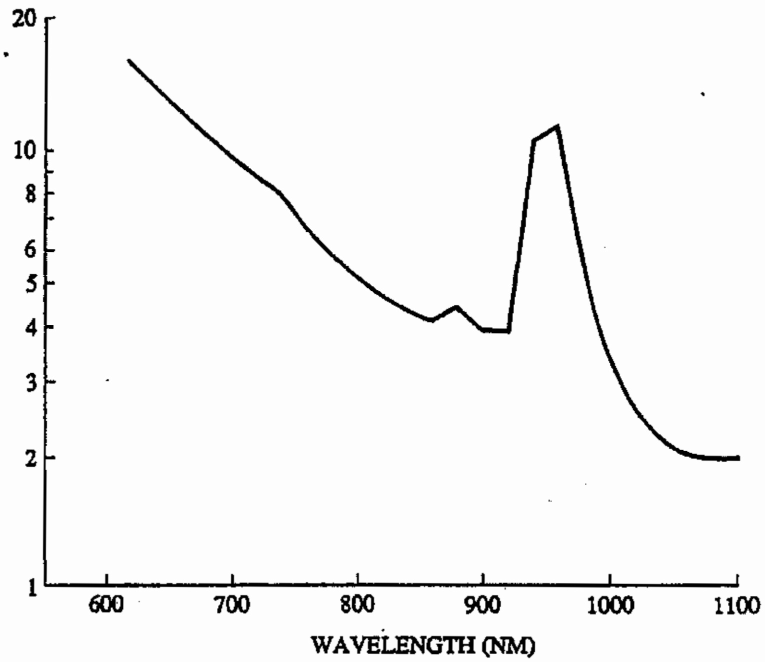
FIG. 4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600
700
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900
1000
1100
WAVELENGTH (NM)

OPTICAL FIBER FABRICATION AND RESULTING PRODUCT

CROSS REFERENCE TO RELATED APPLICATION

This application is a continuation of application Ser. No. 382,401, filed May 26, 1982, now abandoned, which was a continuation of application Ser. No. 147,934, filed May 8, 1980, now abandoned, which was a continuation of application Ser. No. 828,617, filed Aug. 29, 1977, now U.S. Pat. No. 4,217,027, which was a continuation of application Ser. No. 444,705, filed Feb. 22, 1974, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention is concerned with fibers for use in transmission lines in communications systems operating in the visible or near visible spectra. Such fibers are generally clad for guiding purposes so that refractive index decreases in value from the core center to the periphery either as a step function or as a continuous gradient.

2. Description of the Prior Art

"Optical" communications systems, that is systems operating in the visible or near visible spectra, are now at an advanced stage of development. In accordance with the view held by many, commercial use may be expected within a period of about five years.

A system most likely to find initial, and probably long term, use utilizes clad glass fibers as the transmission medium. These fibers, generally having an overall cross-sectional diameter of about 100 mm, are generally composed of at least two sections: core and cladding. The cladding layer is necessarily of lowered refractive index relative to the core with typical index variation from core to clad being in the range from about 0.01 to 0.05. Structures under study may be single mode or multimode. The former is characterized by a sufficiently small core section to efficiently accommodate only the first order mode. Such structures may have a core about 1 or 2 μm. Multimode lines typically have core sections from 50 μm to 85 or 90 μm in diameter.

Multimode structures appear to be of somewhat greater interest at this time. The greater core section facilitates splicing and permits more efficient energy coupling to source and repeater. Introduction of many modes into or, alternatively, generation of many modes within the line does give rise to a dispersion limitation which takes the form of a smearing due to the differing velocities of different order modes. Mode dispersion effects have been minimized by a continuous focusing structure. This structure takes the form of a fiber, the index of which is graded generally exponentially from a high value at the core center. The fundamental mode which traverses the length of material is generally confined to the highest index (lowest velocity) region, while higher order modes as path length increases spend longer and longer periods in relatively low index (high velocity) regions.

A number of procedures have been utilized for fabricating clad glass fibers. Most have yielded to procedures which in some way involve vapor source material. So, typically, chlorides, hydrides, or other compounds of silica, as well as desired dopants, tailoring the index, are reacted with oxygen to produce deposits which directly or ultimately serve as glass source material from which the fiber is drawn. Dopant materials include compounds of, for example, boron for lowering index and germanium, titanium, aluminum, and phosphorus for increasing index. Where the ultimate product is to be a graded multimode line, index gradation may be accomplished, for example, by altering the amount or type of dopant during deposition.

One procedure utilizing vapor source material is chemical vapor deposition (CVD). In this procedure, compounds are passed over a heated surface– e.g., about a rod or within a tube. Temperatures and rates are adjusted so that reaction is solely heterogeneous, i.e., occurs at the heated surface so that the initial material is a continuous glass layer.

An alternative procedure results in the introduction of such precursor materials into a flame produced by ignition of a gaseous mixture of, for example, methane and oxygen. Reaction is, in this instance, homogeneous resulting in formation of glassy particles within the flame. Combustion product and glassy particles then form a moving gas stream which is made incident again on a heated surface, such as a rod or tube. Adherent particles sometimes called "soot" are in subsequent processing flushed, and are sintered and fused to result in a glassy layer.

The CVD process has advantages including high purity but suffers from prolonged required deposition periods. Typically, a suitable preform adequate for fabrication of a kilometer of fiber may require periods of a day or longer.

The soot process has the advantage of high speed; preforms adequate for fabrication of a kilometer of fiber may be prepared in a few hours or less. Disadvantages, however, include at least initial introduction of contaminants, such as solid carbonaceous residue. Since formation takes place within the combustion environment, hydration is inevitable; and this gives rise to the well-known water absorption peaks with their related subharmonics so consequential in various portions of the infrared spectrum.

Both procedures are now an established part of the art. See, for example, U.S. Pat. Nos. 3,711,262, 3,737,292, and 3,737,293. Modifications in the processes have, to some extent, increased the speed of the CVD process and reduced the effects of contamination by hydration in the soot process. Fibers a kilometer or more in length with losses as low as 2 or 3 db/kilometer in selected regions of the infrared are now regularly produced in pilot operations.

SUMMARY OF THE INVENTION

The invention provides for fabrication of clad glass fibers by a procedure which combines some of the advantages of the prior art CVD and soot processes. Generally, gas phase precursor reactants together with oxygen are introduced into a glass tube in the form of a constantly moving stream. Tube and contents are heated to homogeneous reaction temperature within a moving hot zone produced by a moving heating means constantly traversing the outside surface of the tube. Homogeneously produced glass particles ("soot") collect on the tube walls, and are fused into a continuous layer within the moving hot zone.

With usual heating means there is simultaneous heterogeneous reaction so that a glassy layer is produced within the moving hot zone by reaction at the heated wall surface. This deposit, which is present under ordi-

nary circumstances, is identical to the layer produced in the normal CVD processing.

In accordance with the preferred embodiment, the tube within which formation is taking place is continuously rotated about its own axis. For example, at a speed of 100 rpm, uniformity about the periphery is enhanced. The surface produced by the molten CVD layer may help to hold the "soot" particles during fusion.

Reactant materials include chlorides and hydrides, as well as other compounds which will react with oxygen as described. As in other vapor reaction processes, other gaseous material may be introduced, for example, to act as carrier or, in the instance of extremely combustible matter such as hydrides, to act as a diluent.

Continuous fusion within the hot zone and the resultant thickness uniformity of deposit facilitates formation of graded index structures. As in CVD, gradients may be produced by varying reactant composition with the ratio of high index-producing dopant increasing, in this instance, with successive hot zone traversals. Since reaction conditions for different constituents in the reactant mix are different, it is possible also to produce a gradient by altering temperature and/or flow rate during processing.

Typical reaction temperatures maintained at least at the tube wall are within the range of from 1200 to 1600 degrees C. These temperatures, high relative to CVD, are responsible for rapidity of preform production. Particularly at the high temperature end of the range, distortion of the usually silica tube is avoided by rotation. Narrow zones, increased rotation speed, and vertical disposition of the tube may all contribute to the avoidance of tube distortion.

Preforms adequate for preparation of one or a few kilometers of fiber may be prepared during deposition periods of one or a few hours. These preforms are prepared by conventional processing from the deposited product to a final configuration which, as presently practiced, may be of rod shape with an internal diameter of from 4 to 8 mm and a length of 18 inches. In usual processing, the tube which served as the deposition substrate becomes the clad. It may, in accordance with the system, be composed of pure silica or of silica which has been doped to alter, generally to reduce its index. Variations may include removal of the tube, as well as deposition of additional material on the outer surface. The tube serving as the substrate during deposition may be retained to serve as a clad, may be removed, or may, during simultaneous deposition, on its outer surface be provided with encompassing layer/s.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a front elevational view of apparatus suitable for practice of the deposition process in accordance with the invention;

FIG. 2 is a front elevational view of apparatus alternative to that of FIG. 1;

FIG. 3 is a front elevational view of a section of tubular material depicting observed conditions during processing; and

FIG. 4, on coordinates of insertion loss in units of dB/kilometer and wavelength in nanometers, is a plot showing the relationship of those two parameters for a clad multimode fiber produced in accordance with the invention.

DETAILED DESCRIPTION

1. The Drawing

FIG. 1 depicts a lathe 1 holding substrate tube 2 within which a hot zone 3 is produced by heating means 4. Tube 2 may be rotated, for example, in the direction shown by arrow 5a by means now shown and hot zone 3 is caused to traverse tube 2 by movement of heating means 4 as schematically depicted by double headed arrow 5a, for example, by a threaded feed member 6. A gaseous material is introduced into tube 2 via inlet tube 7 which is, in turn, connected to source material reservoirs 8. Such reservoirs may include an oxygen inlet 9 connected to means not shown. As depicted, gaseous material may also be introduced by inlets 10 and 11 by means not shown and through inlet 12 from reservoir 13. Reservoirs 14 and 15 contain normally liquid reactant material which is introduced into tube 2 by means of carrier gas introduced through inlets 10 and 11 with the arrangement being such that the carrier gas is bubbled through such liquids 16 and 17. Exiting material is exhausted through outlet 18. Not shown is the arrangement of mixing valves and shut off valves which may be utilized to meter flows and to make other necessary adjustments in composition. The apparatus of FIG. 1 is generally horizontally disposed.

The apparatus of FIG. 2 is, in its operational characteristic, quite similar to that of FIG. 1. Vertical disposition of the substrate tube, however, lends stability to the portion of the tube within the hot zone and may permit attainment of higher temperature or of longer hot zones in the traversal direction without objectionable distortion. Apparatus depicted includes tube 20 which may optionally be provided with rotation means not shown. This tube is secured to the apparatus by means of chucks 21 and 22 and a traversing hot zone is produced within tube 20 by means of a ring burner 23 which is caused to constantly traverse tube 20 in the direction depicted by double headed arrow 24 by moving means 25. Gaseous material, for example, from source such as 8 of FIG. 1 is introduced via inlet tube 26 and exiting material leaves via exhaust 27.

FIG. 3 is a front elevational view of a section of a substrate tube 30 as observed during deposition. Depicted is a heating means 31 producing a hot zone 32 which is traversing tube 30 in the direction shown by arrow 33 by means now shown. Gaseous material is introduced at the left end of tube 30 and flows in the broken section of the FIG. in the direction shown by arrow 34. For the processing conditions, which with respect to traversal direction and hot zone temperature are those of Example 1, two regions are clearly observable. Zone 35 downstream of hot zone 32 is filled with a moving powdery suspension of particulate oxidic material, while region 36, devoid of such particulate matter, defines the region within which fusion of deposited material is occurring.

FIG. 4 is a plot for measured loss in units of dB/kilometer as measured on 713 meters of fiber prepared in accordance with an Example herein. Abscissa units are wavelength in nanometers. It is seen that loss is at a minimum of about 2 dB/kilometer for the wavelength range of about 1060 to 1100 nm (the limiting value on the plot). The peak at about 950 nm, as well as those at 880 and 730 nm, are characteristic sub-harmonics of the fundamental water absorption.

2. Processing Requirements

a. Reaction Temperature

Superficially, the inventive technique resembles conventional chemical vapor deposition. However, whereas CVD conditions are so arranged that deposi-

tion is solely the result of heterogeneous formation at a heated substrate surface, procedures of this invention rely upon significant homogeneous reaction. In general, 50 percent or more of reaction product is produced in a position removed from substrate surface and results in the formation of solid oxidic particles of the desired glass composition. These particles are similar to those produced during the "soot" process.

Homogeneous reaction is the result of sufficient rate of reactant introduction and sufficient reaction temperature. Such conditions may be achieved simply by increasing one or both parameters until homogeneous reaction is visually observed. To optimize the process from the standpoint of reaction, high temperatures are utilized. For the usual silica based systems which comprise the preferred embodiment, temperatures at least at the substrate wall are generally maintained at a minimum of 1200 degrees C. at the moving position corresponding with the hot zone. Maximum temperatures are ultimately limited by significant wall distortion. For horizontally disposed apparatus, such as that shown in FIG. 1, in which a hot zone of the length of approximately 2 cm moves at the rate of about 45 cm/min within a tube rotated at the rate of about 100 rpm, a temperature of 1600 degrees C. may be produced without harmful tube distortion. Decreasing the length of the hot zone, increasing the rate of rotation, increasing reactant flow rate, vertical disposition of the tube, are all factors which may permit use of higher maximum temperatures without variation in tube geometry. Indicated temperatures are those measured by means of an optical pyrometer focused at the outer tube surface. It has been estimated that for typical conditions the thermal gradient across the tube may be as high as 300 degrees C.

b. Flow Rates

This parameter, like temperature, is dependent upon other processing conditions. Again, a minimum acceptable rate for these purposes may be determined by visual observation. Highest flow rates are for those materials which by virtue of combustibility, high vapor pressure, etc., are diluted to a significant extent by inert material. Examples are the hydrides where dilution frequently is as high as 99.5 volume percent based on the total reactant content may necessitate a linear flow rate of at least 1 meter per second. Chlorides, which do not present this problem, need not be diluted to avoid combustion. Inert material, such as nitrogen or helium, is introduced solely for transfer purposes and need be present only in amount typically of up to 10 percent by volume. Flow rates are, as indicated, temperature dependent, with the required homogeneous reaction taking place at acceptable rate only by an increase flow of about 50 percent for each hundred degree increase in reaction temperature.

c. Reactants

Examples were carried out using chlorides and hydrides. Other gaseous materials of sufficient vapor pressure under processing conditions which react with oxygen or oxygen bearing material to produce the required oxidic glass may be substituted. In a typical system, the substrate tube is silica-generally undoped. Where this tube is of ordinary purity, first reactant introduced may be such as to result in the formation of a first layer of undoped silica or doped with an oxide such as B_2O_3 which serves to lower the refractive index, which acts as a part of the clad and presents a barrier to diffusing impurity from the tube. It may be considered that, under these circumstances, the substrate tube ultimately serves as a mechanical support rather than as an optical cladding. Subsequent to formation of this first barrier layer or absent such procedure, where the tube is of sufficient purity, reactant materials of such nature as to result in the desired index-increased core are introduced. In a chloride system, these may take the form of a mixture of $SiCl_4$ together with, for example $GeCl_4$, and oxygen. Chlorides of other index increasing materials, such as phosphorus, titanium, and aluminum may be substituted for $GeCl_4$ or admixed. BCl_3 may also be included perhaps to facilitate glass formation because of lowered fusion temperature; or because of refractive index lowering, the initial mixture may be altered during successive hot zone traversals so as to increase index (by increasing $GeCl_4$ or other index-increasing dopant precursor or by decreasing BCl_3).

Since the usual vapor phase glass precursor compounds are not oxidic, oxygen or a suitable oxygen bearing compound is generally included to form the ultimate oxidic glass. A satisfactory procedure, followed in exemplary procedures, takes the form of an oxygen stream bubbled through reservoirs of liquid phase glass forming compounds. In one procedure, for example, oxygen streams were bubbled through silicon tetrachloride, and through germanium tetrachloride. These streams were then combined with vapor phase boron tetrachloride and additional oxygen, the resultant mixture being introduced into the reaction chamber.

Relative amounts of glass forming ingredients are dependent upon a variety of factors, such as vapor pressure, temperature, flow rate, desired index, etc. The appended examples indicate suitable amounts for producing the noted indices under the noted conditions. Variants are known to those familiar with glass forming procedures.

A variety of diluent materials may be utilized for any of the noted reasons so, for example, argon, nitrogen, helium, etc., may serve to maintain desired flow rates to prevent precombustion, etc. Oxygen bearing compounds which may replace oxygen in whole or in part include N_2O, NO, and CO_2.

In general, concentration of 3d-transition metal impurities in the gas stream is kept below 10^{-2} percent, although further reduction in loss accompanies reduction of those impurities down to the part per billion range. Such levels are readily available from commercial sources or by purification by means similar to those taught by H. C. Theuerer, Pat. No. 3,071,444. As compared with the usual soot process, the inventive procedure is carried out in a controlled environment without direct exposure to combustion products. This inherently results in avoidance of inclusion of particulate combustion products. Where desired, hydration resulting from combustion in the soot process may be minimized. This is a particularly significant advantage for operation in several portions of the infrared spectrum which suffers from sub-harmonics of the fundamental H_2O absorption. Water vapor may, therefore, be a particularly significant impurity and, for many purposes, should be kept to a level below a few ppm by volume.

3. General Procedure

The procedure described is that which was followed in Examples 1 through 4. Deposition was carried out within a 12 I.D. by 14 O.D. mm silica tube. The tube was placed on a glass lathe within which it was rotated at 100 rpm. Before introduction of reactants, it was flushed with a continuous stream of oxygen while tra-

versing with an oxyhydrogen burner sufficient to bring the wall temperature to 1400 degrees C. The purpose was to remove any volatile impurities on the inside wall of the tube.

Following a period of 5 minutes, a mixture of oxygen, $SiCl_4$, and BCl_3 replaced the oxygen flow. The composition of approximately 10 percent $SiCl_4$, 3 percent BCl_3, remainder oxygen, maintaining temperature at 1400 degrees C. within the moving hot zone as measured at the wall. In this particular example, the zone was moved at a speed of approximately 45 cm/min in the forward direction (direction of gas flow) and was rapidly returned to its initial position (approximately 30sec. elapsed time to the beginning of the slow traversal).

Formation of flaky material within the tube, at a position spaced from the wall generally downstream of the hot zone, was visually observed. It was deduced and verified that homogeneous reaction was largely within the zone with particulates being carried downstream by the moving gas. Deposition was continued for approximately twenty minutes following which flow of chloride reactants was discontinued. Oxygen flow was continued for several passes of the hot zone.

The procedure to this point results in deposition of a layer serving as cladding. Core material was next deposited by introduction of $SiCl_4$ and $GeCl_4$. These reactants, too, were introduced with an oxygen carrier, as before. With the temperature of the hot zone increased somewhat to about 1450 degrees C., deposition was continued for about one hour.

In this particular example, tube collapse was initiated with reactants still flowing simply by reducing the rate of traverse of the hot zone. This resulted in a temperature increase which ultimately attained a level of about 1900 degrees C. to produce nearly complete collapse. Reactant flow was then stopped with final collapse producing a finished preform consisting of a GeO_2-SiO_2 core with a borosilicate cladding supported, in turn, by a silica layer. It will be recognized by those skilled in the art of fiber drawing, that the tube, without first being collapsed, can also be drawn into acceptable fiber. The resulting preform was then drawn to result in a fiber having an overall diameter of approximately 100 μm with a core area defined as the region within the borosilicate layer having a diameter of approximately 37 μm. The length of fiber drawn was approximately 0.7 km. The method described in some detail in N. S. Kapany, *Fiber Optics Principles and Applications* (Academic Press, N.Y.) (1967) pages 110–117, involved the local heating of an end of the preform which was affixed to the fiber, which was, in turn, drawn at a constant velocity of approximately 60 meters/min by winding on a 30 cm diameter mandrel rotating at 60rpm.

The above description is in exemplary terms and is usefully read in conjunction with the appended examples. The inventive process departs from conventional CVD as described—i.e., in that reactant introduction rate and temperature are such as to result in homogeneous reaction to produce oxidic particles within the space enclosed, but separated from the walls of a tube. This, when combined with a moving hot zone, results in rapid preparation of a high quality preform as described. The moving hot zone is responsible for (1) homogeneous reaction; (2) to a large extent, the adherence of oxidic particles to the wall; and (3) fusion of the deposited particles and CVD-produced layer into a unitary, homogeneous glassy layer. In general, it is desirable to maintain the hot zone as short as possible depending upon constancy of traversal speed to result in uniform layer production. Motion of the hot zone should be such that every portion of the tube is heated to the zone temperature for the same period of time. This is easily accomplished by passing the heating means through a traversal distance which extends beyond the tube at both ends. Experimentally, hot zones of the order of 2 cm length (defining the heated region extending 4 cm on either side of the peak) have resulted in uniform coating under all experimental conditions. While, in principle, heating the entire tube may result in uniformity of deposition approaching that attained by use of a moving zone, very high flow rates are required to avoid inhomogeneity and differing thickness of deposit along the length of the tube.

4. Examples

The following example, utilizing chloride or hydride reactants, are set forth. The selection was made with a view to demonstrating a wide variety of compositions and different types of optical waveguide preforms for which the procedure can be used.

The tube of commercial grade fused quartz was first cleaned by immersion in hydrofluoric acid-nitric acid solution for three minutes and was rinsed with deionized water for a period of one hour. Tubing was cut into 18"lengths, and such sections were utilized in each of the examples. The substrate tube was provided with appropriate input and exhaust sections, and was heated with a moving oxyhydrogen torch producing a hot zone which traversed the tube in from one to eight minutes. In each instance, flushing was by oxygen at a flow rate of between 100 and 500 cm^3/min corresponding with a linear rate of 4.5 meter/mins, and this flushing was continued for several traversals of the zone.

EXAMPLE 1

The fused quartz tube used in this example was 12 mm I.D. × 14 mm O.D. Initial deposition was of a cladding material, SiO_2-B_2O_3, by introduction of 41 cm^3/min. $SiCl_4$, 12.5 cm^3/min BCl^3, both carried by oxygen such that the total oxygen flow was 250 cc/min. Sixteen passes of the hot zone were made at a temperature of 1430 degrees C. Core material was next deposited by flows of 32 cc/min $SiCl_4$, 48 cc/min $GeCl_4$, and oxygen 650 cc/min. This was continued for 68 minutes and temperatures of the hot zone were maintained at 1460 degrees C. Remaining steps, including partial collapse with flowing gas and final collapse under no flow conditions, were as specified under Section 3. The fiber that resulted from this procedure had a core of approximately 40 μm with an overall diameter of approximately 100 μm. Its length was 723 meters and optical attenuation was 2 dB/km at 1060–1100 nm.

EXAMPLE 2

A fused quartz tube 6 mm I.D. ×8 mm O.D. was cleaned as described and positioned in a glass lathe. Flows of diluted (1 percent by volume in N_2) silane, germane, diborane, and oxygen were passed through the tube as follows:

SiH_4: 1,000 cc/min.
GeH_4: 150 cc/min.
B_2H_6: 50 cc/min.

Deposition commenced by heating the tube locally using an oxyhydrogen flame which was traversed along the length of the tube. The complete cycle took 3.7 minutes, and the highest temperature attained was 1400

degrees C. After 175 minutes, the gas flows were stopped and the tube collapsed in one additional pass, made at a much slower rate. Temperatures achieved here were in the vicinity of 1750–1900 degrees C. The preform was removed to a pulling apparatus and drawn to a fiber whose diameter was 100microns overall. This consisted of a core whose composition was SiO_2-GeO_2-B_2O_3 of approximately 25 microns diameter. The cladding had the composition of SiO_2. The index difference produced by the core was 0.007.

EXAMPLE 3

A clean fused silica tube 6 mm I.D. ×8 mm O.D. was positioned in a glass lathe was previously described. Flows of diluted (3.05 percent by volume in N_2) silane, diborane, and oxygen were passed through the tube as follows:

SiH_4: 295 cc/min.
B_2H_6: 49 cc/min.
O_2: 900 cc/min.

Deposition commenced by heating the tube locally using an oxyhydrogen torch which traversed along the tube at a rate of 0.10 cm/sec as the tube rotated at 100–120 rpm. The torch was adjusted so as to produce a temperature locally of 1375–1450 degrees C. When the torch had moved to the end of the tube, it was returned at 0.15 cm/sec with the SiH_4 and B_2H_6 flows stopped. This procedure continued for three hours. At this time the B_2H_6 flow was stopped and just SiH_4 and O_2 continued. At the same time, the torch was adjusted to produce temperatures of 1600–1650 degrees C., other conditions remaining the same as previously. Depositing the pure SiO_2 layer continued for 1.5 hours.

At this time, silane flow was stopped and just O_2 flow continued at 600 cc/min. Temperatures were varied during the next two passes to 1650–1700 degrees C. Now the oxygen was stopped, the traverse slowed to 0.05 cm/sec, and the temperature raised to 1850–1890 degrees C. to bring about complete collapse of the tube.

This procedure produced a preform having a core of pure SiO_2, a cladding layer of B_2O_3-SiO_2, and an outer jacket of commercial grade SiO_2. The fiber drawn from this preform had a core of 30 μm, cladding thickness of 15 μm and an outer jacket of 20 μm, with an index difference of 0.007 percent and losses of 3 dB/km at 1.06 μm wavelength.

EXAMPLE 4

For optical communications employing multimode optical fibers it is desirable to more nearly equalize the group velocities of propagating modes. This result is expected if the index of the core is gradually increased from the cladding toward the interior of the core. To accomplish this an 8 mm I. D. ×10 mm O.D. fused quartz tube was positioned and borosilicate layer intended to serve as a portion of the cladding and as a barrier layer was deposited as in Example 1. Next deposition of the GeO_2-B_2O_3-SiO_2 core was commenced except that the germania content was gradually increased from zero during the period of deposition. The conditions used during the deposition were as follows:

Barrier layer
$SiCl_4$: 32 cc/min
BCl_3: 12.5 cc/min
O_2: 250 cc/min
Temp: 1740 degrees C.
Time: 25 min.

Graded Index portion of the core
$SiCl_4$: 33 cc/min
BCl_3:
12.5 7.5 cc/min
17 equal increments at
2 min intervals
$GeCl_4$:
0–35 cc/min
17 equal increments at
2 min intervals
O_2:
460–830 cc/min
17 equal increments at
2 min intervals
Temp: 1470 degrees C.

Constant Index portion of core
$SiCl_4$: 32 cc/min
BCl_3: 7.5 cc/min
$GeCl_4$: 35 cc/min
O_2: 830 cc/min
Temp: 1470 degrees C.
Time: 53 min.

At the conclusion of the deposition, the tube was collapsed to yield a solid preform which was then pulled to yield an optical fiber. When the mode dispersion of this fiber was measured, it behaved in a manner expected of a graded index. This behavior can be expressed by relation (Bell System Technical Journal 52, pp. 1566 (1973)) $\eta = \eta_0[1 - 2\Delta(r/a)^\alpha]^{\frac{1}{2}}$ where in this instance the value of $\alpha = 5$.

What is claimed is:

1. A method of making an optical fiber preform suitable for drawing into an optical fiber including the steps of: providing a hollow glass tube of a first refractive index and having a predetermined length with a bore formed therethrough; introducing into said bore, in unreacted dry vapor form, material that forms a glass layer, coating said bore by thermally depositing said material thereon to form a glass layer of higher refractive index than the refractive index of said tube; rotating said glass tube about its longitudinal axis by a rotating device, while heating said coated tube to collapse said tube into a solid preform having substantially the same length as said predetermined length whereby the glass coating layer becomes a core of said higher index of refraction than the refractive index of said tube.

2. The method of making an optical fiber preform as set forth in claim 1, wherein said tube is made of a silica glass and wherein said material includes germania and silica in order to produce an optical fiber preform having a core of mixed germania-silica composition.

3. The method of claim 1 wherein the coating, rotating and heating steps occur in the order recited.

4. A process for fabrication of a glass optical fiber preform having a core section and a cladding comprising the steps of: introducing a moving stream of a vapor mixture including at least one compound glass forming precursor together with an oxidizing medium into a tube of a predetermined length, heating the tube and contents by a moving hot zone produced by a correspondingly moving heat source external to the tube so as to react the said mixture and produce a glassy layer on the inner surface of the tube, rotating said glass tube about its longitudinal axis by a rotating device, while heating said coated tube to collapse said tube into a solid preform having substantially the same length as said predetermined length whereby the glass coating layer becomes a core having a higher index of refraction than the refractive index of said tube.

5. The process of claim 4 wherein said vapor mixture includes oxygen and chlorides of silicon and germanium.

6. The process of claim 4 wherein the first mentioned heating, the rotating and the second mentioned heating steps occur in the order recited.

7. A method of making an optical fiber preform having a glass core and a glass cladding comprising the steps of: introducing a stream of vapors into the interior of a glass tube having a first refractive index and a predetermined length, said vapor being chemically reactive in the process of heating to form glass substantially similar to that of said glass core, establishing a localized hot zone in the interior of said glass tube to react vapor within said hot zone, moving said hot zone longitudinally along substantially the same length of said glass tube to coat a layer of glass substantially similar to said glass core on the inside wall of said glass tube, rotating said glass tube about its longitudinal axis by a rotating device, while heating said coated tube to collapse said tube into a solid preform having substantially the same length as said predetermined length whereby the glass coating layer becomes a core having a higher index of refraction than the refractive index of said tube.

8. The method of claim 7 wherein the moving, rotating and heating steps occur in the order recited.

9. A method of making an optical fiber preform suitable for drawing into an optical fiber including the steps of:

providing a hollow glass tube of a first refractive index and having a predetermined length with a bore formed therethrough;

introducing into said bore, in unreacted dry vapor form, material that forms a glass layer,

coating said bore by thermally depositing said material thereon to form a glass layer of higher refractive index than the refractive index of said tube;

rotating said coated glass tube about its longitudinal axis by a rotating device; and

heating said rotating coated tube to collapse said tube into a solid preform having substantially the same length as said predetermined length whereby the glass coating layer becomes a core of said higher index of refraction than the refractive index of said tube.

10. The method of claim 9 wherein said heating step is accomplished by passing a heat source along the length of said tube.

11. The method of claim 10 wherein said core includes germania and silica.

12. A process for fabrication of a glass optical fiber preform having a core section and a cladding comprising the steps of:

introducing a moving stream of a vapor mixture including at least one compound glass forming precursor together with an oxidizing medium into a tube of a predetermined length,

heating the tube and contents by a moving hot zone produced by a correspondingly moving heat source external to the tube so as to react the said mixture and produce a glassy layer on the inner surface of the tube,

rotating said coated glass tube about its longitudinal axis by a rotating device; and

heating said rotating coated tube to collapse said tube into a solid preform having substantially the same length as said predetermined length whereby the glass coating layer becomes a core having a higher index of refraction than the refractive index of said tube.

13. The process of claim 12 wherein the second-mentioned heating step is accomplished by passing a heat source along the length of said tube.

14. The process of claim 12 wherein said core includes germania and silica.

15. A method of making an optical fiber preform having a glass core and a glass cladding comprising the steps of:

introducing a stream of vapors into the interior of a glass tube having a first refractive index and a predetermined length, said vapor being chemically reactive in the process of heating to form glass substantially similar to that of said glass core,

establishing a localized hot zone in the interior of said glass tube to react vapor within said hot zone,

moving said hot zone longitudinally along substantially the same length of said glass tube to coat a layer of glass substantially similar to said glass core on the inside wall of said glass tube,

rotating said coated glass tube about its longitudinal axis by a rotating device; and

heating said rotating coated tube to collapse said tube into a solid preform having substantially the same length as said predetermined length whereby the glass coating layer becomes a core having a higher index of refraction than the refractive index of said tube.

16. The method of claim 15 wherein said heating step is accomplished by passing a heat source along the length of said tube.

17. The method of claim 15 wherein said core includes germania and silica.

* * * * *

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United States Patent [19]

Hart, Jr. et al.

[11] Patent Number: 5,298,047

[45] Date of Patent: Mar. 29, 1994

[54] METHOD OF MAKING A FIBER HAVING LOW POLARIZATION MODE DISPERSION DUE TO A PERMANENT SPIN

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[73] Assignee: **AT&T Bell Laboratories**, Murray Hill, N.J.

[21] Appl. No.: **924,278**

[22] Filed: **Aug. 3, 1992**

[51] **Int. Cl.**[5] **C03B 37/025**

[52] **U.S. Cl.** **65/3.11; 65/3.43;** 65/34; 65/10.1; 264/1.5

[58] **Field of Search** 264/1.5; 65/3.11, 3.4, 65/3.43, 3.44, 3.2, 3.12, 10.1

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,028,081	6/1977	Marcatili	65/3.11
4,205,899	6/1980	King	264/1.5
4,308,045	12/1981	Miller	65/3.11
4,341,442	7/1982	Johnson .	
4,427,717	1/1984	Gauthier	65/3.11
4,504,300	3/1985	Gauthier	65/10.1
4,509,968	4/1985	Arditty	65/10.1
4,572,840	2/1986	Gombert	65/3.11
4,606,605	8/1986	Ashkin .	
4,884,859	12/1989	Yamamoto	65/2

OTHER PUBLICATIONS

Ulrich, "Single-mode fiber-optical polarization rotator" Jun. 1979/vol. 18, No. 11/Applied Optics.

"Outer Diameter Measurement of Low Birefringence Optical Fibers by a New Resonant Backscatter Technique", by A. Ashkin et al., *Applied Optics*, vol. 20, No. 13, Jul. 1, 1981, pp. 2299–2303.

"Birefringence and Polarization Mode-Dispersion in Spun Single-Mode Fibers", by A. J. Barlow et al., *Applied Optics*, vol. 20, No. 17, Sep. 1, 1981, pp. 2962–2968.

"Preservation of Polarization in Single-Mode Fibers", by S. C. Rashleigh, *Laser Focus*, May 1983.

"Origins and Control of Polarization Effects in Single-Mode Fibers", by S. C. Rashleigh, *Journal of Lightwave Technology*, vol. LT-1, No. 2, Jun. 1983, pp. 312–331.

"Internal Rotation of the Birefringence Axes in Polarization-Holding Fibers", by M. J. Marrone et al., *Optics Letters*, vol. 12, No. 1, Jan. 1987, pp. 60–62.

PCT Application: PCT/GB82/00200, filed Jul. 7, 1982, Publication No. WO 83/00232, published Jan. 20, 1983.

Primary Examiner—W. Gary Jones
Assistant Examiner—John Hoffmann
Attorney, Agent, or Firm—Eugen E. Pacher

[57] **ABSTRACT**

The presence of (typically unintended) birefringence in single mode optical fiber can severely limit the usefulness of the fiber for, e.g., high bit rate or analog optical fiber communication systems, due to the resulting polarization mode dispersion (PMD). It has now been discovered that PMD can be substantially reduced if, during drawing of the fiber, a torque is applied to the fiber such that a "spin" is impressed on the fiber. Desirably the torque is applied such that the spin impressed on the fiber does not have constant spatial frequency, e.g., has alternately clockwise and counterclockwise helicity. At least a portion of optical fiber according to the invention has a spin whose spatial frequency exceeds 4 spins/meter.

4 Claims, 3 Drawing Sheets

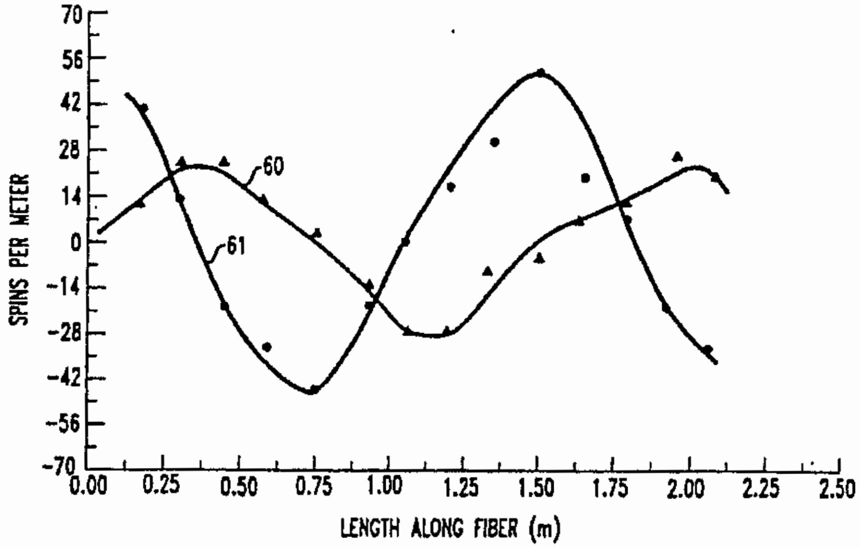


FIG. 1
(PRIOR ART)

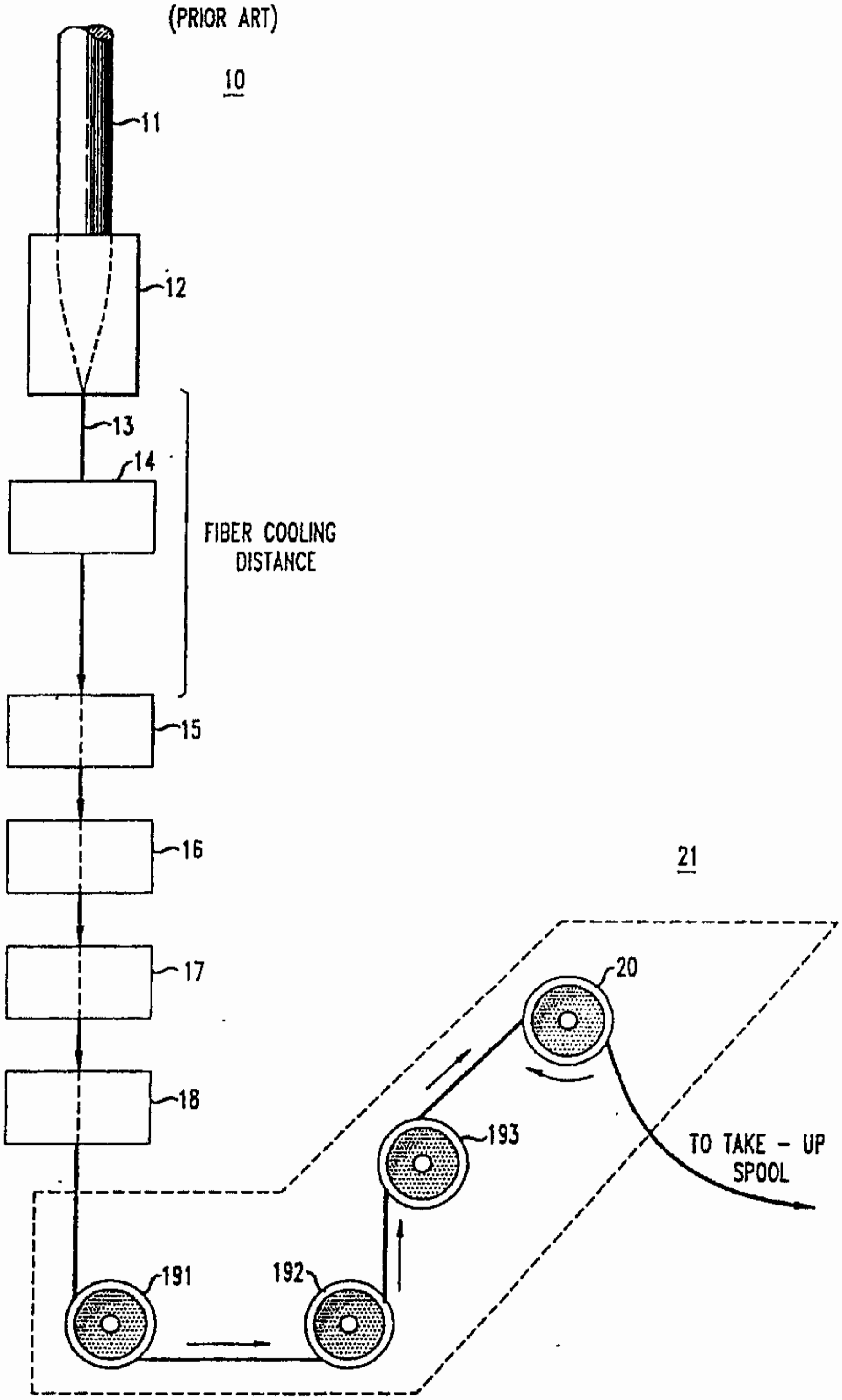


FIG. 2
(PRIOR ART)

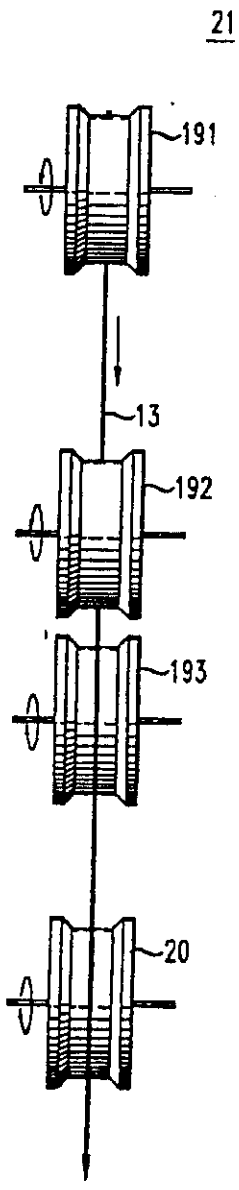


FIG. 3

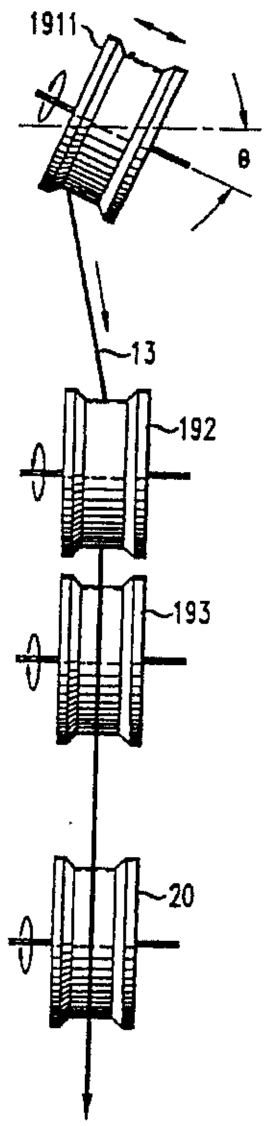


FIG. 4

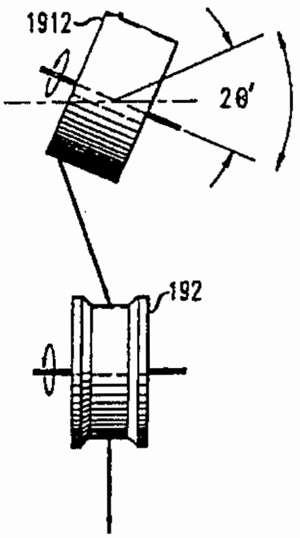


FIG. 5

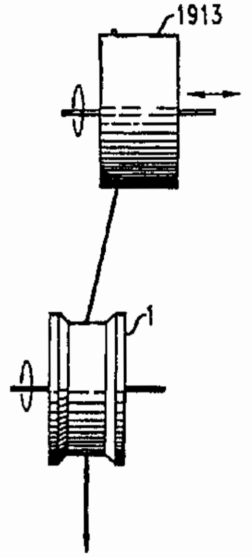
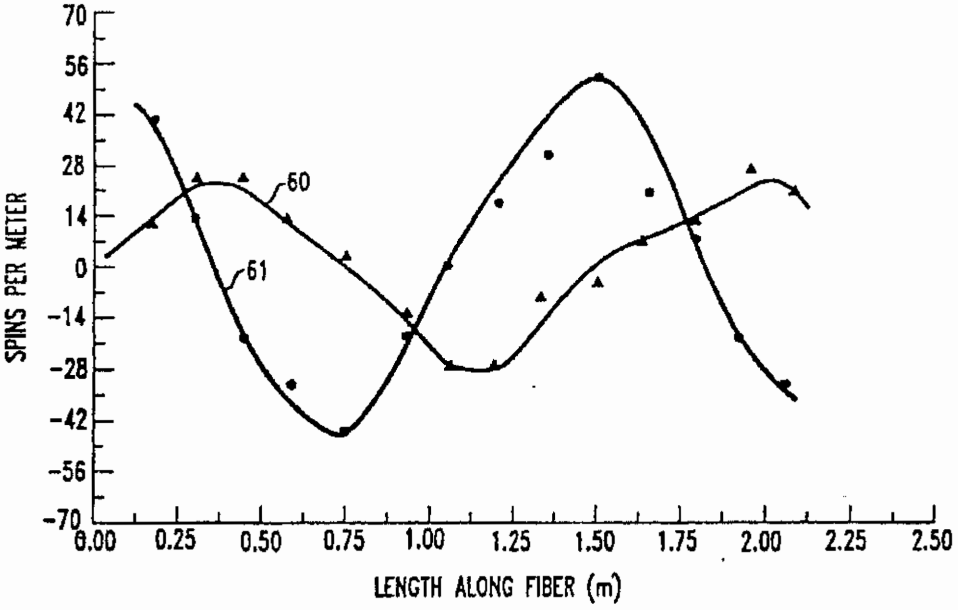


FIG. 6



METHOD OF MAKING A FIBER HAVING LOW POLARIZATION MODE DISPERSION DUE TO A PERMANENT SPIN

FIELD OF THE INVENTION

This invention pertains to optical fibers, in particular, to single mode optical fiber having relatively low polarization mode dispersion (PMD). It also pertains to communication systems that comprise such fiber, and to methods of making such fiber.

BACKGROUND OF THE INVENTION

An ideal circularly symmetric "single mode" optical fiber can support two independent, degenerate modes of orthogonal polarization. Either one of these constitutes the fundamental HE_{11} mode. In general, the electric field of light propagating along the fiber is a linear superposition of these two polarization eigenmodes.

In practical single mode fiber, various imperfections such as asymmetrical lateral stress and a non-circular core typically break the circular symmetry of the ideal fiber and lift the degeneracy of these two polarization modes. The two modes then propagate with different phase velocities, and this difference between their effective refractive indices is called birefringence.

Fiber birefringence can result from either a geometrical deformation or from various elasto-optic, magneto-optic or electro-optic index changes. In so-called polarization-preserving fibers asymmetry is deliberately introduced into the fiber. However, in ordinary (non-polarization-preserving) fibers the birefringence mechanisms act on the fiber in substantially unpredictable manner. Thus, the polarization state of the guided light will typically evolve through a pseudorandom sequence of states along the fiber, with the polarization state at the fiber output typically being both unpredictable and unstable. On average, a given polarization state in a given fiber is reproduced after a certain length L_p, the polarization "beat" length associated with the given fiber.

The presence of birefringence in conventional single mode fiber results in signal dispersion (so-called polarization mode dispersion or PMD) and thus typically is undesirable, especially for applications that involve high bit rates or analog transmission (e.g., for optical fiber analog CATV systems).

It is known that fiber having low PMD can be produced by rapidly spinning the preform while pulling the fiber from the preform. The prior art teaches that this results in periodically interchanged fast and slow birefringence axes along the fiber, which can lead to very low net birefringence due to piecemeal compensation of the relative phase delay between the polarization eigenmodes, provided the spin pitch is much less than the "un-spun" fiber beat length. See, for instance, A. Ashkin et al., *Applied Optics*, Vol. 20(13), p. 2299; A. J. Barlow et al., *Applied Optics*, Vol. 20(17), p. 2962; and S. C. Rashleigh, *Laser Focus*, May 1983.

It is primarily the prior art requirement that the spin pitch be much less than the "unspun" L_p which makes the prior art technique substantially unsuitable for current commercial fiber production. For instance, assuming that the unspun L_p is about 1 m and the draw speed is 10 m/seconds, then the preform has to be spun at 6000 rpm in order to yield a spin pitch that is 1/10th of the unspun L_p. This is typically not practical in commercial fiber production.

In view of the commercial significance of low birefringence optical fiber, it would be highly desirable to have available a technique for producing such fiber that is compatible with current commercial practice, e.g., that is usable even at the high draw speeds that are typically used now. This application discloses such a technique.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 schematically depicts exemplary prior art fiber draw apparatus;

FIG. 2 shows, schematically and in top view, the guide portion of the apparatus of FIG. 1;

FIGS. 3–5 depict, also schematically and in top view, exemplary guide portions that can be used to practice the invention; and

FIG. 6 shows exemplary data on spin vs. distance along the fiber, for fiber according to the invention.

THE INVENTION

Broadly speaking, the invention is embodied in a novel and convenient method of making optical fiber, typically single mode fiber, that can be used to produce fiber having low PMD, exemplarily less than 0.5 ps/km$^{\frac{1}{2}}$. It is also embodied in a novel type of low PMD fiber, and in articles (e.g., an optical fiber communication system) that comprise such fiber.

More specifically, the inventive method comprises providing a conventional optical fiber preform, heating at least a portion of the preform to a conventional draw temperature, and drawing optical fiber from the heated preform in such a way that a spin is impressed on the fiber. Significantly, a torque is applied to the fiber such that the fiber is caused to twist around its longitudinal axis, with a resulting torsional deformation of the fiber material in the hot zone.

A spin is "impressed" on the fiber herein if fiber material in the hot zone is caused to be torsionally deformed, with the deformation being frozen into the fiber, such that the fiber exhibits a permanent "spin", i.e., a permanent torsional deformation. The existence of such a frozen-in spin can be readily ascertained, e.g., by microscopic examination of the fiber to determine rotation of core ovality or eccentricity, or by means of a traveling magneto-optic modulator, as used by M. J. Marrone et al., *Optics Letters*, Vol. 12(1), p. 60. Associated with such a frozen-in spin is a pitch, the spin repeat distance along the fiber.

As will be readily appreciated by those skilled in the art, the prior art method of spinning the preform results in a spin of essentially constant pitch. It is known that small twists of the symmetry axes can occur during the drawing process such that even conventional single-mode fibers exhibit a variation in the optical polarization along the fiber. See, for instance, the above cited Marrone et al. paper. However, we know of no case of prior art fiber with unintended spin whose spin had a spatial frequency in excess of 4 spins/meter. See, for instance, M. J. Marrone et al., op. cit., Table 1. Fiber having such low spin typically does not exhibit commercially significant reduction in PMD. Thus, fiber according to the invention comprises a portion or portions having spin spatial frequency in excess of 4 spins/meter, preferably in excess of 10 or even 20 spins/meter.

In currently preferred embodiments of the invention, the torque is applied intermittently to the fiber, whereby the spin impressed on the fiber has a pitch that is not constant over substantial lengths of fiber, e.g., is not constant over the beat length L_p. We currently believe that non-constant pitch can have advantages over constant pitch, since low pitch can also couple the two polarization modes, provided the pitch is precisely matched with the fiber birefringence spatial frequency. See, for instance, S. C. Rashleigh, J. of *Lightwave Technology*, Vol. LT-1(2), pp. 312–331, especially p. 320, where it is stated that, ". . . regardless of the actual distribution f(z) of the birefringence perturbations, only the one spectral component with frequency β_i can couple the two polarization eigenmodes. All other spectral components do not efficiently couple the modes". The parameter β_i is the intrinsic birefringence of the fiber, and $F(\beta_i)$ is the Fourier transform of f(z). Since the perturbation f(z) is essentially random, it is clear that a constant pitch spin will typically not result in efficient mode coupling. On the other hand, non-constant pitch spin, especially spin that has alternately positive and negative helicity, is likely to contain spatial components that produce efficient coupling. We currently believe that strong coupling can be obtained with spin of varying spatial frequency that comprises, in addition to regions of relatively high spin spatial frequency, regions of relatively low spin spatial frequency. This is, for instance, the case if the spin alternates between positive and negative helicity.

The invention is also embodied in optical fiber (exemplarily SiO_2-based fiber comprising a core and a cladding, with the former having larger effective refractive index than the cladding material that surrounds the core) that is produced by the inventive method. It is also embodied in an article (e.g., an optical fiber communication system that comprises a source of an optical signal, means for detecting an optical signal, and an optical fiber according to the invention signal-transmissively connecting the detector means and the source. More specifically, a spin is impressed on the fiber, with the spin not being constant along the fiber, and with at least a portion of the fiber having a spatial spin frequency in excess of 4 spins/meter.

FIG. 1 schematically depicts conventional (prior art) drawing apparatus 10. Fiber preform 11 is slowly fed (by means of a feed mechanism that is not shown) into furnace 12, where fiber 13 is drawn from the necked down portion of the preform. The bare fiber passes through diameter monitor 14 into coating applicator 15, wherein the polymer coating (frequently comprising an inner and an outer coating) is applied to the, by now relatively cool, bare fiber. After passing through coating concentricity monitor 16 the fiber passes through curing station 17. Exemplarily 17 comprises UV lamps. Downstream from 17 is coating diameter monitor 18, followed by guide means (e.g., rollers 191, 192, 193) and drive means (e.g., pulling capstan 20) in region 21. It will be noted that guide roller 191 is the first contact point of the fiber with a solid. At this point the fiber is already protected by a cured polymer coating. It will also be noted that the draw force is provided by capstan 20, and that the rotational speed of 20 determines the draw speed, which exemplarily can be as high as 20 m/second. From 20 the fiber typically is lead to (independently driven) take-up means, e.g., a take-up spool. Those skilled in the art will recognize that FIG. 1 shows several optional features (e.g., 14, 16, 18), and does not show all possible features (e.g., a hermetic coating chamber between 12 and 15). However, FIG. 1 exemplifies currently used conventional drawing apparatus.

In the prior art apparatus of FIG. 1 the fiber essentially moves in a single plane at least between its point of origin in the furnace and the capstan, and no twist is intentionally impressed on the fiber. See FIG. 2, which is a schematic top view of portion 21 of the apparatus of FIG. 1.

According to the invention, a torque is applied to the fiber such that a spin is impressed on the fiber. Although in principle the torque could be applied at any downstream point (prior to take-up) at which the fiber has cooled sufficiently to be contacted, it is generally not desirable to contact the bare fiber. Thus, the torque advantageously is applied at a point downstream from curing station 17, typically at an appropriate point in region 21. It is currently most preferred to apply the torque by means of the first guide roller.

We have discovered that an intermittent torque can be applied to the fiber, such that a twist with non-constant pitch is impressed on the fiber. This can, for instance, be accomplished by changing the orientation of guide roller 1911 of FIG. 3, exemplarily by canting the roller by an angle θ around a direction parallel to the draw tower axis. Canting roller 1911 as indicated causes the fiber to oscillate back and forth on the roller, in response to lateral forces that automatically arise in this arrangement. More specifically, the lateral forces translate into a torque on the fiber, which causes the fiber to roll laterally on roller 1911, thereby moving the fiber out of the plane defined by the fiber in the prior art (un-canted) apparatus. It will be appreciated that the lateral roll is superimposed on the conventional draw motion. The lateral motion of the fiber is believed to give rise to a restoring force that increases with increasing lateral displacement of the fiber, causing the fiber to jump back (substantially, but not necessarily exactly) into the plane, only to immediately begin another sidewise roll. This non-symmetrical back-and-forth motion is indicated by the double-headed arrow adjacent to roller 1911 in FIG. 3. The angular rotation speed of the fiber during the lateral roll is, inter alia, a function of the cant angle θ. Thus, the pitch of the spin impressed on the fiber is also a function of θ. For instance, particular draw apparatus used by us yielded average pitches of 14 and 7 cm for $\theta=7°$ and 15°, respectively. It will be appreciated that these values are exemplary only, since the pitch will depend, inter alia, on the configuration and height of the draw tower, the draw speed, the draw tension and the coating viscosity.

Those skilled in the art will recognize that the described exemplary method not only impresses a spin on the fiber but also introduces a substantially equal and opposite (generally elastic) twist into the taken-up fiber. Although such fiber may be acceptable for some purposes (e.g., for sensor purposes that require only a relatively short length of fiber), it will generally be desirable to remove (or prevent the introduction of) the unwanted elastic twist. The elastic twist can, for instance, be removed by appropriate respooling. However, it is preferable to substantially prevent introduction of the elastic twist. This can be accomplished by alternately imposing a clockwise and a counterclockwise torque on the fiber, exemplarily as described below.

Causing the guide roller 1912 of FIG. 4 to oscillate about an axis that is parallel to the fiber draw direction

(which is typically the same as the draw tower axis) alternately impresses positive and negative spin on the fiber. Furthermore, the resulting positive and negative elastic twists on the fiber substantially cancel, such that the fiber on the take-up spool is substantially free of torsional elastic strain. Guide roller 1912 of FIG. 4 can be caused to oscillate back and forth by any appropriate means, e.g., by eccentric drive means (not shown). An alternate arrangement is schematically shown in FIG. 5, wherein guide roller 1913 is caused to move back and forth axially, by appropriate conventional means that are not shown, resulting in alternate application of clockwise and counterclockwise torque on the fiber.

Those skilled in the art will recognize that the guide and drive means 21 of FIG. 1 can take many forms. For instance, sheaves (as shown in FIGS. 1-3) may be used, or ungrooved rollers may be used, or sheaves and ungrooved rollers may be used in combination (exemplarily as shown in FIGS. 4 and 5). All appropriate guide and drive means are contemplated, as are all appropriate means for applying an appropriate torque to the fiber.

FIG. 6 shows exemplary experimental data, namely, the spin spatial frequency (in spins/m) as a function of distance along the fiber. Curve 60 was obtained from a single mode fiber which was drawn at 1.5 m/second, with 60 cycles/minute of the oscillating guide roller 1912 of FIG. 4), and curve 61 from an otherwise identical single mode fiber which was drawn at 3 m/second, with 106 cycles/minute of roller 1912. As can be seen from FIG. 6, each of the fibers contains portions whose spin spatial frequency is far in excess of 4 spins/m (even in excess of 20 spins/m), and in each of the fibers the spin is non-constant, even having clockwise and counterclockwise helicity, resulting in substantial likelihood that the spin comprises a component that is effective in coupling the two polarization modes.

Those skilled in the art will appreciate that the pitch of the spin impressed on fiber drawn in apparatus of the type shown in FIG. 4 depends, inter alia, on the oscillation amplitude $2\theta'$ and the oscillation frequency. For instance, in a particular fiber draw apparatus according to the invention θ' was about 15°, and the oscillation frequency was about 106 cycles/minute. These values are exemplary only, and those skilled in the art will, aided by the teachings herein, be able to not only adapt their draw apparatus to practice the invention but also to select draw parameters that are suitable for their particular apparatus.

We claim:

1. A method of making an optical fiber comprising
a) providing an optical fiber preform;
b) heating at least a portion of said preform; and
c) drawing optical fiber from the heated preform such that a spin is impressed on the fiber; wherein
d) step c) comprises, while maintaining the preform rotationally stationary, applying a torque to the fiber, said torque causing the fiber to undergo rotation around the longitudinal axis of the fiber such that the spin is impressed on the fiber as it is drawn from the preform, wherein the torque is applied such that the spin impressed on the fiber does not have a constant spatial frequency.

2. Method according to claim 1, wherein the torque is alternately applied in clockwise and counterclockwise direction, such that the spin impressed on the fiber is alternately clockwise and counterclockwise.

3. Method according to claim 2, wherein step c) comprises coating the fiber with a polymer coating and causing the coated fiber to contact a guide roller, wherein the alternating torque is applied by means of said guide roller.

4. Method according to claim 3, wherein applying the torque by means of the guide roller comprises causing the guide roller to oscillate about an axis that is substantially parallel to a fiber draw direction.

* * * * *

US005418881A

United States Patent [19]

Hart, Jr. et al.

[11] Patent Number: 5,418,881

[45] Date of Patent: May 23, 1995

[54] ARTICLE COMPRISING OPTICAL FIBER HAVING LOW POLARIZATION MODE DISPERSION, DUE TO PERMANENT SPIN

[75] Inventors: Arthur C. Hart, Jr., Chester; Richard G. Huff, Basking Ridge; Kenneth L. Walker, New Providence, all of N.J.

[73] Assignee: AT&T Corp., Murray Hill, N.J.

[21] Appl. No.: 317,409

[22] Filed: Oct. 3, 1994

Related U.S. Application Data

[60] Continuation of Ser. No. 164,525, Dec. 9, 1993, abandoned, which is a division of Ser. No. 924,278, Aug. 3, 1992, Pat. No. 5,298,047.

[51] Int. Cl.^{6} G02B 6/10

[52] U.S. Cl. 385/123; 385/111; 385/11; 65/432; 65/438

[58] Field of Search 385/123, 100, 110, 111, 385/113, 11, 15; 65/3.11, 10.1, 438, 432, 435; 359/494, 498, 885; 57/6, 7, 9, 293; 264/1.5; 356/73.1, 364

[56] References Cited

U.S. PATENT DOCUMENTS

4,028,081	6/1977	Marcatili	65/2
4,154,049	5/1979	King et al.	385/100 X
4,205,899	6/1980	King et al.	350/96.23
4,248,035	2/1981	Skillen et al.	385/100 X
4,308,045	12/1981	Miller	65/3.11
4,341,442	7/1982	Johnson	350/96.30
4,427,717	1/1984	Gauthier	427/163
4,504,300	3/1985	Gauthier et al.	65/10.1
4,509,968	4/1985	Arditty et al.	65/10.1
4,556,314	12/1985	Stone	356/73.1
4,572,840	2/1986	Gombert et al.	427/36
4,606,605	8/1986	Ashkin et al.	350/96.31
4,884,859	12/1989	Yamamoto et al.	350/96.15
5,227,623	7/1993	Heffner	356/364

OTHER PUBLICATIONS

Patent Abstracts of Japan, vol. 13, No. 187 (C-592) 2 May 1989 and JP-A-01 014 126 (Hitachi Cable Ltd.) 18 Jan. 1989.

PCT Application: PCT/GB82/00200, filed Jul. 7, 1982, Publication No. WO 83/00232, published Jan. 20, 1983.

"Outer Diameter Measurement of Low Birefringence Optical Fibers by a New Resonant Backscatter Technique", by A. Ashkin et al., *Applied Optics*, 1 Jul. 1981, vol. 20, No. 13, pp. 2299-2303.

"Birefringence and Polarization Mode-Dispersion in Spun Single-Mode Fibers", by A. J. Barlow et al., *Applied Optics*, vol. 20, No. 17, Sep. 1, 1981, pp. 2962-2968.

"Preservation of Polarization in Single-Mode Fibers", by S. C. Rashleigh et al., *Laser Focus*, May 1983 issue, 6 pages.

"Origins and Control of Polarization Effects in Single-Mode Fibers", by S. C. Rashleigh, *Journal of Lightwave Technology*, vol. LT-1, No. 2, Jun. 1983, pp. 312-331.

"Internal Rotation of the Birefringence Axes in Polarization-Holding Fibers", by M. J. Marrone et al., *Optics Letters*, vol. 12, No. 1, Jan. 1987, pp. 60-62.

"Technique for Controlling the Internal Rotation of Principal Axes in the Fabrication of Birefringent Fibers", by C. G. Askins et al., *Journal of Lightwave Technology*, vol. 6, No. 9, Sep. 1988, pp. 1402-1405.

"Fabrication of Circularly Birefringent Single Mode Fibers", by S.C.Rashleigh, Navy Technical Disclosure Bulletin, vol. 5, No. 12 (1980), 8 pages.

European Search Repot, The Hague, Sep. 29, 1993, Examiner J. G. Stroud.

Primary Examiner—Frank Gonzalez
Assistant Examiner—Phan Thi Heartney Palmer
Attorney, Agent, or Firm—Eugen E. Pacher

[57] ABSTRACT

The presence of (typically unintended) birefringence in single mode optical fiber can severely limit the usefulness of the fiber for, e.g., high bit rate or analog optical fiber communication systems, due to the resulting polarization mode dispersion (PMD). It has now been discovered that PMD can be substantially reduced if, during drawing of the fiber, a torque is applied to the fiber such that a "spin" is impressed on the fiber. Desirably the torque is applied such that the spin impressed on the fiber does not have constant spatial frequency, e.g., has alternately clockwise and counterclockwise helicity. At least a portion of optical fiber according to the invention has spin alternately clockwise and counterclockwise.

4 Claims, 3 Drawing Sheets

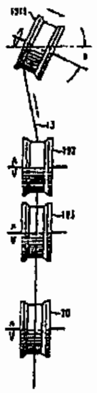


FIG. 1
(PRIOR ART)

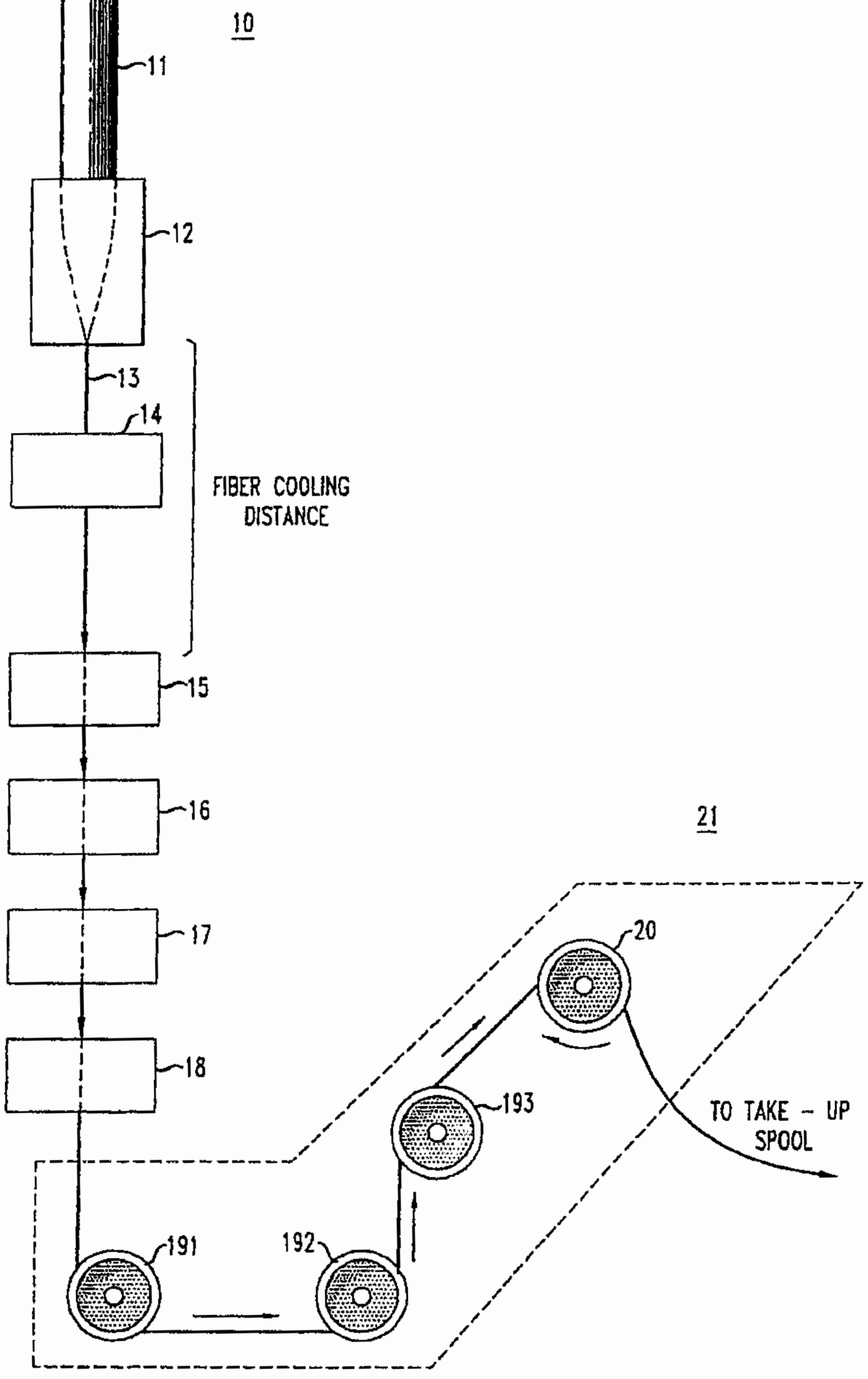


FIG. 2
(PRIOR ART)

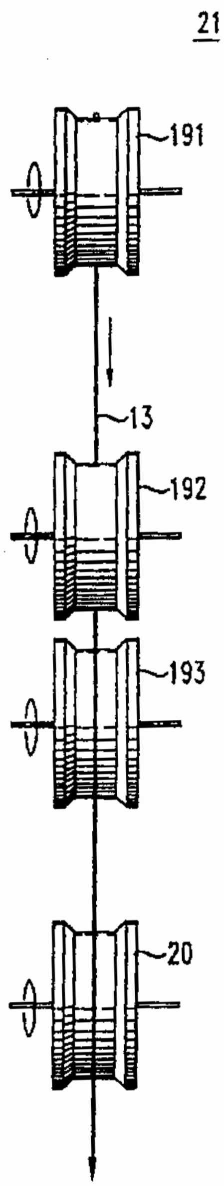
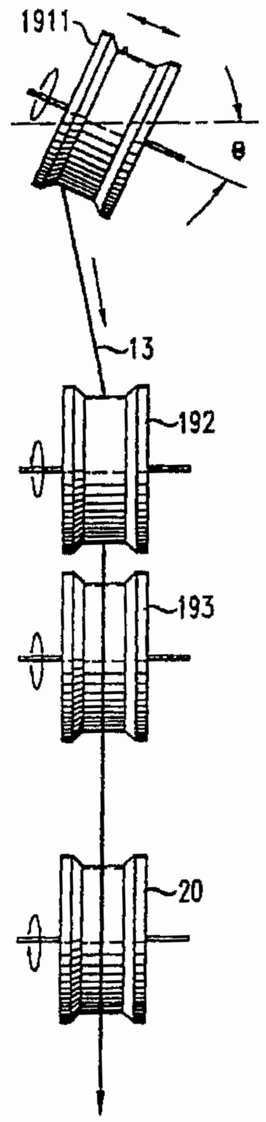


FIG. 3



3/3

FIG. 4

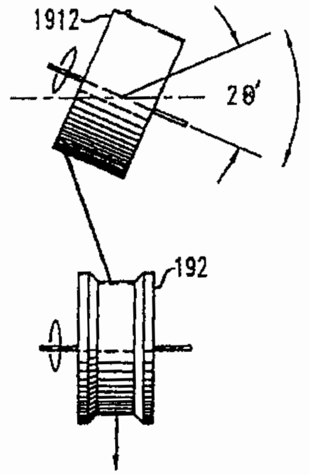


FIG. 5

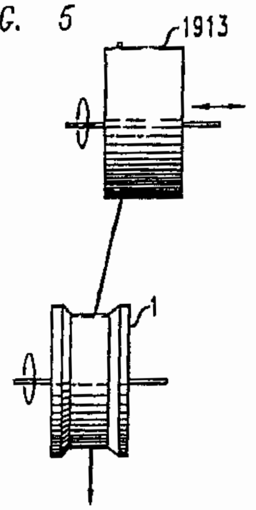


FIG. 6

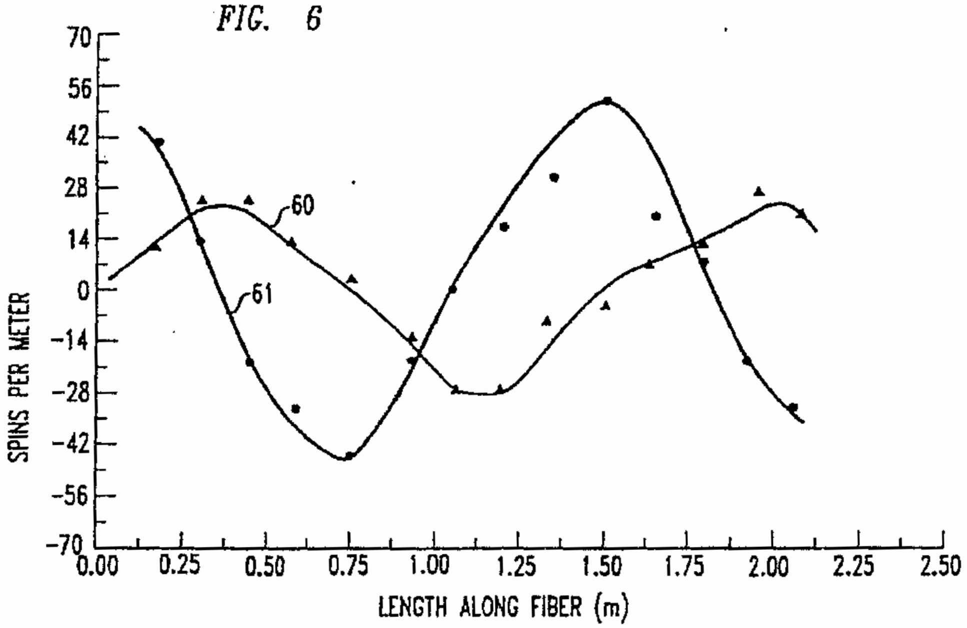
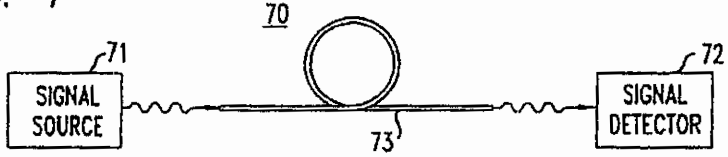


FIG. 7



ARTICLE COMPRISING OPTICAL FIBER HAVING LOW POLARIZATION MODE DISPERSION, DUE TO PERMANENT SPIN

This application is a continuation of application Ser. No. 08/164,525, filed on Dec. 9, 1993, now abandoned, which was a divisional application under 37 CFR 1.60, Ser. No. 07/924,278, filed Aug. 3, 1992, now U.S. Pat. No. 5,298,047.

FIELD OF THE INVENTION

This invention pertains to optical fibers, in particular, to single mode optical fiber having relatively low polarization mode dispersion (PMD). It also pertains to communication systems that comprise such fiber, and to methods of making such fiber.

BACKGROUND OF THE INVENTION

An ideal circularly symmetric "single mode" optical fiber can support two independent, degenerate modes of orthogonal polarization. Either one of these constitutes the fundamental HE_{11} mode. In general, the electric field of light propagating along the fiber is a linear superposition of these two polarization eigenmodes.

In practical single mode fiber, various imperfections such as asymmetrical lateral stress and a non-circular core typically break the circular symmetry of the ideal fiber and lift the degeneracy of these two polarization modes. The two modes then propagate with different phase velocities, and this difference between their effective refractive indices is called birefringence.

Fiber birefringence can result from either a geometrical deformation or from various elasto-optic, magneto-optic or electro-optic index changes. In so-called polarization-preserving fibers asymmetry is deliberately introduced into the fiber. However, in ordinary (non-polarization-preserving) fibers the birefringence mechanisms act on the fiber in substantially unpredictable manner. Thus, the polarization state of the guided light will typically evolve through a pseudorandom sequence of states along the fiber, with the polarization state at the fiber output typically being both unpredictable and unstable. On average, a given polarization state in a given fiber is reproduced after a certain length L_p, the polarization "beat" length associated with the given fiber.

The presence of birefringence in conventional single mode fiber results in signal dispersion (so-called polarization mode dispersion or PMD) and thus typically is undesirable, especially for applications that involve high bit rates or analog transmission (e.g., for optical fiber analog CATV systems).

It is known that fiber having low PMD can be produced by rapidly spinning the preform while pulling the fiber from the preform. The prior art teaches that this results in periodically interchanged fast and slow birefringence axes along the fiber, which can lead to very low net birefringence due to piecemeal compensation of the relative phase delay between the polarization eigenmodes, provided the spin pitch is much less than the "un-spun" fiber beat length. See, for instance, A. Ashkin et al., *Applied Optics*, Vol. 20(13), p. 2299; A. J. Barlow et al., *Applied Optics*, Vol. 20(17), p. 2962; and S. C. Rashleigh, Laser Focus, May 1983.

It is primarily the prior art requirement that the spin pitch be much less than the "unspun" L_p which makes the prior art technique substantially unsuitable for current commercial fiber production. For instance, assuming that the unspun L_p is about 1 m and the draw speed is 10 m/seconds, then the preform has to be spun at 6000 rpm in order to yield a spin pitch that is 1/10th of the unspun L_p. This is typically not practical in commercial fiber production.

In view of the commercial significance of low birefringence optical fiber, it would be highly desirable to have available a technique for producing such fiber that is compatible with current commercial practice, e.g., that is usable even at the high draw speeds that are typically used now. This application discloses such a technique.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 schematically depicts exemplary prior art fiber draw apparatus;

FIG. 2 shows, schematically and in top view, the guide portion of the apparatus of FIG. 1;

FIGS. 3–5 depict, also schematically and in top view, exemplary guide portions that can be used to practice the invention;

FIG. 6 shows exemplary data on spin vs. distance along the fiber, for fiber according to the invention; and

FIG. 7 schematically depicts an exemplary optical communication system according to the invention.

THE INVENTION

Broadly speaking, the invention is embodied in a novel and convenient method of making optical fiber, typically single mode fiber, that can be used to produce fiber having low PMD, exemplarily less than 0.5 ps/km$^{\frac{1}{2}}$. It is also embodied in a novel type of low PMD fiber, and in articles (e.g., an optical fiber communication system) that comprise such fiber.

More specifically, the inventive method comprises providing a conventional optical fiber preform, heating at least a portion of the preform to a conventional draw temperature, and drawing optical fiber from the heated preform in such a way that a spin is impressed on the fiber. Significantly, a torque is applied to the fiber such that the fiber is caused to twist around its longitudinal axis, with a resulting torsional deformation of the fiber material in the hot zone.

A spin is "impressed" on the fiber herein if fiber material in the hot zone is caused to be torsionally deformed, with that deformation being frozen into the fiber, such that the fiber exhibits a permanent "spin", i.e., a permanent torsional deformation. The existence of such a frozen-in spin can be readily ascertained, e.g., by microscopic examination of the fiber to determine rotation of core ovality or eccentricity, or by means of a traveling magneto-optic modulator, as used by M. J. Marrone et al., *Optics Letters*, Vol. 12(1), p. 60. Associated with such a frozen-in spin is a pitch, the spin repeat distance along the fiber.

As will be readily appreciated by those skilled in the art, the prior art method of spinning the preform results in a spin of essentially constant pitch. It is known that small twists of the symmetry axes can occur during the drawing process such that even conventional single-mode fibers exhibit a variation in the optical polarization along the fiber. See, for instance, the above cited Marrone et al. paper. However, we know of no case of prior art fiber with unintended spin whose spin had a spatial frequency in excess of 4 spins/meter. See, for instance, M. J. Marrone et al., op. cit., Table 1. Fiber having such low spin typically does not exhibit com-

mercially significant reduction in PMD. Thus, fiber according to the invention comprises a portion or portions having spin spatial frequency in excess of 4 spins/meter, preferably in excess of 10 or even 20 spins/meter.

In currently preferred embodiments of the invention, the torque is applied intermittently to the fiber, whereby the spin impressed on the fiber has a pitch that is not constant over substantial lengths of fiber, e.g., is not constant over the beat length L_p. We currently believe that non-constant pitch can have advantages over constant pitch, since low pitch can also couple the two polarization modes, provided the pitch is precisely matched with the fiber birefringence spatial frequency. See, for instance, S.C. Rashleigh,

J. of Lightwave Technology, Vol. LT-1(2), pp. 312-331, especially p. 320, where it is stated that, "... regardless of the actual distribution f(z) of the birefringence perturbations, only the one spectral component with frequency β_i can couple the two polarization eigenmodes. All other spectral components do not efficiently couple the modes". The parameter β_i is the intrinsic birefringence of the fiber, and $F(\beta_i)$ is the Fourier transform of f(z). Since the perturbation f(z) is essentially random, it is clear that a constant pitch spin will typically not result in efficient mode coupling. On the other hand, non-constant pitch spin, especially spin that has alternately positive and negative helicity, is likely to contain spatial components that produce efficient coupling. We currently believe that strong coupling can be obtained with spin of varying spatial frequency that comprises, in addition to regions of relatively high spin spatial frequency, regions of relatively low spin spatial frequency. This is, for instance, the case if the spin alternates between positive and negative helicity.

The invention is also embodied in optical fiber (exemplarily SiO_2-based fiber comprising a core and a cladding, with the former having larger effective refractive index than the cladding material that surrounds the core) that is produced by the inventive method. It is also embodied in an article (e.g., an optical fiber communication system that comprises a source of an optical signal, means for detecting an optical signal, and an optical fiber according to the invention signal-transmissively connecting the detector means and the source. More specifically, a spin is impressed on the fiber, with the spin not being constant along the fiber, and with at least a portion of the fiber having a spatial spin frequency in excess of 4 spins/meter.

FIG. 1 schematically depicts conventional (prior art) drawing apparatus 10. Fiber preform 11 is slowly fed (by means of a feed mechanism that is not shown) into furnace 12, where fiber 13 is drawn from the necked down portion of the preform. The bare fiber passes through diameter monitor 14 into coating applicator 15, wherein the polymer coating (frequently comprising an inner and an outer coating) is applied to the, by now relatively cool, bare fiber. After passing through coating concentricity monitor 16 the fiber passes through curing station 17. Exemplarily 17 comprises UV lamps. Downstream from 17 is coating diameter monitor 18, followed by guide means (e.g., rollers 191, 192, 193) and drive means (e.g., pulling capstan 20) in region 21. It will be noted that guide roller 191 is the first contact point of the fiber with a solid. At this point the fiber is already protected by a cured polymer coating. It will also be noted that the draw force is provided by capstan 20, and that the rotational speed of 20 determines the draw speed, which exemplarily can be as high as 20 m/second. From 20 the fiber typically is lead to (independently driven) take-up means, e.g., a take-up spool. Those skilled in the art will recognize that FIG. 1 shows several optional features (e.g., 14, 16, 18), and does not show all possible features (e.g., a hermetic coating chamber between 12 and 15). However, FIG. 10 exemplifies currently used conventional drawing apparatus.

In the prior an apparatus of FIG. 1 the fiber essentially moves in a single plane at least between its point of origin in the furnace and the capstan, and no twist is intentionally impressed on the fiber. See FIG. 2, which is a schematic top view of portion 21 of the apparatus of FIG. 1.

According to the invention, a torque is applied to the fiber such that a spin is impressed on the fiber. Although in principle the torque could be applied at any downstream point (prior to take-up) at which the fiber has cooled sufficiently to be contacted, it is generally not desirable to contact the bare fiber. Thus, the torque advantageously is applied at a point downstream from curing station 17, typically at an appropriate point in region 21. It is currently most preferred to apply the torque by means of the first guide roller.

We have discovered that an intermittent torque can be applied to the fiber, such that a twist with non-constant pitch is impressed on the fiber. This can, for instance, be accomplished by changing the orientation of guide roller 1911 of FIG. 3, exemplarily by canting the roller by an angle θ around a direction parallel to the draw tower axis. Canting roller 1911 as indicated causes the fiber to oscillate back and forth on the roller, in response to lateral forces that automatically arise in this arrangement. More specifically, the lateral forces translate into a torque on the fiber, which causes the fiber to roll laterally on roller 1911, thereby moving the fiber out of the plane defined by the fiber in the prior an (un-canted) apparatus. It will be appreciated that the lateral roll is superimposed on the conventional draw motion. The lateral motion of the fiber is believed to give rise to a restoring force that increases with increasing lateral displacement of the fiber, causing the fiber to jump back (substantially, but not necessarily exactly) into the plane, only to immediately begin another sidewise roll. This non-symmetrical back-and-forth motion is indicated by the double-headed arrow adjacent to roller 1911 in FIG. 3. The angular rotation speed of the fiber during the lateral roll is, inter alia, a function of the cant angle θ. Thus, the pitch of the spin impressed on the fiber is also a function of θ. For instance, particular draw apparatus used by us yielded average pitches of 14 and 7 cm for $\theta=7$ and 15°, respectively. It will be appreciated that these values are exemplary only, since the pitch will depend, inter alia, on the configuration and height of the draw tower, the draw speed, the draw tension and the coating viscosity.

Those skilled in the art will recognize that the described exemplary method not only impresses a spin on the fiber but also introduces a substantially equal and opposite (generally elastic) twist into the taken-up fiber. Although such fiber may be acceptable for some purposes (e.g., for sensor purposes that require only a relatively short length of fiber), it will generally be desirable to remove (or prevent the introduction of) the unwanted elastic twist. The elastic twist can, for instance, be removed by appropriate respooling. However, it is preferable to substantially prevent introduc-

tion of the elastic twist. This can be accomplished by alternately imposing a clockwise and a counterclockwise torque on the fiber, exemplarily as described below.

Causing the guide roller 1912 of FIG. 4 to oscillate about an axis that is parallel to the fiber draw direction (which is typically the same as the draw tower axis) alternately impresses positive and negative spin on the fiber. Furthermore, the resulting positive and negative elastic twists on the fiber substantially cancel, such that the fiber on the take-up spool is substantially free of torsional elastic strain. Guide roller 1912 of FIG. 4 can be caused to oscillate back and forth by any appropriate means, e.g., by eccentric drive means (not shown). An alternate arrangement is schematically shown in FIG. 5, wherein guide roller 1913 is caused to move back and forth axially, by appropriate conventional means that are not shown, resulting in alternate application of clockwise and counterclockwise torque on the fiber.

Those skilled in the art will recognize that the guide and drive means 21 of FIG. 1 can take many forms. For instance, sheaves (as shown in FIGS. 1-3) may be used, or ungrooved rollers may be used, or sheaves and ungrooved rollers may be used in combination (exemplarily as shown in FIGS. 4 and 5). All appropriate guide and drive means are contemplated, as are all appropriate means for applying an appropriate torque to the fiber.

FIG. 6 shows exemplary experimental data, namely, the spin spatial frequency (in spins/m) as a function of distance along the fiber. Curve 60 was obtained from a single mode fiber which was drawn at 1.5 m/second, with 60 cycles/minute of the oscillating guide roller 1912 of FIG. 4), and curve 61 from an otherwise identical single mode fiber which was drawn at 3 m/second, with 106 cycles/minute of roller 1912. As can be seen from FIG. 6, each of the fibers contains portions whose spin spatial frequency is far in excess of 4 spins/m (even in excess of 20 spins/m), and in each of the fibers the spin is non-constant, even having clockwise and counterclockwise helicity, resulting in substantial likelihood that the spin comprises a component that is effective in coupling the two polarization modes.

Those skilled in the art will appreciate that the pitch of the spin impressed on fiber drawn in apparatus of the type shown in FIG. 4 depends, inter alia, on the oscillation amplitude $2\theta'$ and the oscillation frequency. For instance, in a particular fiber draw apparatus according to the invention θ' was about 15°, and the oscillation frequency was about 106 cycles/minute. These values are exemplary only, and those skilled in the art will, aided by the teachings herein, be able to not only adapt their draw apparatus to practice the invention but also to select draw parameters that are suitable for their particular apparatus. FIG. 7 shows an exemplary optical communication system 70 according to the invention wherein numerals 71-73 refer, respectively, to an optical signal source, an optical signal detector, and optical fiber that signal transmissively connects source and detector.

We claim:

1. An article comprising optical communication fiber with a spin impressed on the fiber; CHARACTERIZED IN THAT the fiber is single mode optical fiber; and in at least a portion of the fiber the spin impressed on the fiber is alternately clockwise and counterclockwise, with a spin repeat distance of at most 20 m.

2. Article according to claim 1, wherein said single mode optical fiber has a polarization mode dispersion (PMD), with the PMD of the fiber being less than 0.5 ps/km$^{\frac{1}{2}}$.

3. Article according to claim 2, wherein the article is an optical communication system that comprises an optical signal source a length of optical fiber comprising said single mode optical fiber and an optical signal detector, with said length optical fiber signal-transmissively connecting said source and said detector.

4. Article according to claim 1, wherein the repeat distance is at most 13.2 m.

* * * * *

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JS 44 (Rev. 11/04)

CIVIL COVER SHEET

The JS 44 civil cover sheet and the information contained herein neither replace nor supplement the filing and service of pleadings or other papers as required by law, except as provided by local rules of court. This form, approved by the Judicial Conference of the United States in September 1974, is required for the use of the Clerk of Court for the purpose of initiating the civil docket sheet. (SEE INSTRUCTIONS ON THE REVERSE OF THE FORM.)

I. (a) PLAINTIFFS

FURUKAWA ELECTRIC NORTH AMERICA, INC.
OFS FITEL LLC

(b) County of Residence of First Listed Plaintiff (EXCEPT IN U.S. PLAINTIFF CASES)

(c) Attorney's (Firm Name, Address, and Telephone Number)

Sarah Chapin Columbia, Carlos Perez-Albuerne, Choate, Hall & Stewart LLP, Two International Place, Boston, MA 02110

6/16/05 M.E.

DEFENDANTS

ANTARES DEVELOPMENT INTERNATIONAL LLC

County of Residence of First Listed Defendant
(IN U.S. PLAINTIFF CASES ONLY)

NOTE: IN LAND CONDEMNATION CASES, USE THE LOCATION OF THE LAND INVOLVED.

Attorneys (If Known)

05 CA 11665 RGS

II. BASIS OF JURISDICTION (Place an "X" in One Box Only)

- ☐ 1 U.S. Government Plaintiff
- ☒ 3 Federal Question (U.S. Government Not a Party)
- ☐ 2 U.S. Government Defendant
- ☐ 4 Diversity (Indicate Citizenship of Parties in Item III)

III. CITIZENSHIP OF PRINCIPAL PARTIES (Place an "X" in One Box for Plaintiff and One Box for Defendant) (For Diversity Cases Only)

	PTF	DEF		PTF	DEF
Citizen of This State	☐ 1	☐ 1	Incorporated or Principal Place of Business In This State	☐ 4	☐ 4
Citizen of Another State	☐ 2	☐ 2	Incorporated and Principal Place of Business In Another State	☐ 5	☐ 5
Citizen or Subject of a Foreign Country	☐ 3	☐ 3	Foreign Nation	☐ 6	☐ 6

IV. NATURE OF SUIT (Place an "X" in One Box Only)

CONTRACT
- ☐ 110 Insurance
- ☐ 120 Marine
- ☐ 130 Miller Act
- ☐ 140 Negotiable Instrument
- ☐ 150 Recovery of Overpayment & Enforcement of Judgment
- ☐ 151 Medicare Act
- ☐ 152 Recovery of Defaulted Student Loans (Excl. Veterans)
- ☐ 153 Recovery of Overpayment of Veteran's Benefits
- ☐ 160 Stockholders' Suits
- ☐ 190 Other Contract
- ☐ 195 Contract Product Liability
- ☐ 196 Franchise

REAL PROPERTY
- ☐ 210 Land Condemnation
- ☐ 220 Foreclosure
- ☐ 230 Rent Lease & Ejectment
- ☐ 240 Torts to Land
- ☐ 245 Tort Product Liability
- ☐ 290 All Other Real Property

TORTS

PERSONAL INJURY
- ☐ 310 Airplane
- ☐ 315 Airplane Product Liability
- ☐ 320 Assault, Libel & Slander
- ☐ 330 Federal Employers' Liability
- ☐ 340 Marine
- ☐ 345 Marine Product Liability
- ☐ 350 Motor Vehicle
- ☐ 355 Motor Vehicle Product Liability
- ☐ 360 Other Personal Injury

PERSONAL INJURY
- ☐ 362 Personal Injury - Med. Malpractice
- ☐ 365 Personal Injury - Product Liability
- ☐ 368 Asbestos Personal Injury Product Liability

PERSONAL PROPERTY
- ☐ 370 Other Fraud
- ☐ 371 Truth in Lending
- ☐ 380 Other Personal Property Damage
- ☐ 385 Property Damage Product Liability

CIVIL RIGHTS
- ☐ 441 Voting
- ☐ 442 Employment
- ☐ 443 Housing/ Accommodations
- ☐ 444 Welfare
- ☐ 445 Amer. w/Disabilities - Employment
- ☐ 446 Amer. w/Disabilities - Other
- ☐ 440 Other Civil Rights

PRISONER PETITIONS
- ☐ 510 Motions to Vacate Sentence

Habeas Corpus:
- ☐ 530 General
- ☐ 535 Death Penalty
- ☐ 540 Mandamus & Other
- ☐ 550 Civil Rights
- ☐ 555 Prison Condition

FORFEITURE/PENALTY
- ☐ 610 Agriculture
- ☐ 620 Other Food & Drug
- ☐ 625 Drug Related Seizure of Property 21 USC 881
- ☐ 630 Liquor Laws
- ☐ 640 R.R. & Truck
- ☐ 650 Airline Regs.
- ☐ 660 Occupational Safety/Health
- ☐ 690 Other

LABOR
- ☐ 710 Fair Labor Standards Act
- ☐ 720 Labor/Mgmt. Relations
- ☐ 730 Labor/Mgmt.Reporting & Disclosure Act
- ☐ 740 Railway Labor Act
- ☐ 790 Other Labor Litigation
- ☐ 791 Empl. Ret. Inc. Security Act

BANKRUPTCY
- ☐ 422 Appeal 28 USC 158
- ☐ 423 Withdrawal 28 USC 157

PROPERTY RIGHTS
- ☐ 820 Copyrights
- ☒ 830 Patent
- ☐ 840 Trademark

SOCIAL SECURITY
- ☐ 861 HIA (1395ff)
- ☐ 862 Black Lung (923)
- ☐ 863 DIWC/DIWW (405(g))
- ☐ 864 SSID Title XVI
- ☐ 865 RSI (405(g))

FEDERAL TAX SUITS
- ☐ 870 Taxes (U.S. Plaintiff or Defendant)
- ☐ 871 IRS—Third Party 26 USC 7609

OTHER STATUTES
- ☐ 400 State Reapportionment
- ☐ 410 Antitrust
- ☐ 430 Banks and Banking
- ☐ 450 Commerce
- ☐ 460 Deportation
- ☐ 470 Racketeer Influenced and Corrupt Organizations
- ☐ 480 Consumer Credit
- ☐ 490 Cable/Sat TV
- ☐ 810 Selective Service
- ☐ 850 Securities/Commodities/ Exchange
- ☐ 875 Customer Challenge 12 USC 3410
- ☐ 890 Other Statutory Actions
- ☐ 891 Agricultural Acts
- ☐ 892 Economic Stabilization Act
- ☐ 893 Environmental Matters
- ☐ 894 Energy Allocation Act
- ☐ 895 Freedom of Information Act
- ☐ 900Appeal of Fee Determination Under Equal Access to Justice
- ☐ 950 Constitutionality of State Statutes

V. ORIGIN (Place an "X" in One Box Only)

☒ 1 Original Proceeding ☐ 2 Removed from State Court ☐ 3 Remanded from Appellate Court ☐ 4 Reinstated or Reopened ☐ 5 Transferred from another district (specify) ☐ 6 Multidistrict Litigation ☐ 7 Appeal to District Judge from Magistrate Judgment

VI. CAUSE OF ACTION

Cite the U.S. Civil Statute under which you are filing (Do not cite jurisdictional statutes unless diversity):

Brief description of cause:
This action is for patent infringement arising under the patent laws of the United States, U.S.C. Title 35

VII. REQUESTED IN COMPLAINT:

☐ CHECK IF THIS IS A CLASS ACTION UNDER F.R.C.P. 23

DEMAND $

CHECK YES only if demanded in complaint:
JURY DEMAND: ☑ Yes ☐ No

VIII. RELATED CASE(S) IF ANY

(See instructions): JUDGE Richard Stearns DOCKET NUMBER 05-11219-RGS

DATE 8/11/05

SIGNATURE OF ATTORNEY OF RECORD [signature]

FOR OFFICE USE ONLY

RECEIPT # ________ AMOUNT ________ APPLYING IFP ________ JUDGE ________ MAG. JUDGE ________

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6/2/05
M.P.

UNITED STATES DISTRICT COURT
DISTRICT OF MASSACHUSETTS

05 CA 11665 RGS

1. Title of case (name of first party on each side only) Furukawa Electric North America, Inc.; OFS Fitel LLC v. Antares Development International LLC

2. Category in which the case belongs based upon the numbered nature of suit code listed on the civil cover sheet. (See local rule 40.1(a)(1)).

- [ ] I. 160, 410, 470, 535, R.23, REGARDLESS OF NATURE OF SUIT.
- [x] II. 195, 196, 368, 400, 440, 441-446, 540, 550, 555, 625, 710, 720, 730, 740, 790, 791, 820*, 830*, 840*, 850, 890, 892-894, 895, 950. *Also complete AO 120 or AO 121 for patent, trademark or copyright cases
- [ ] III. 110, 120, 130, 140, 151, 190, 210, 230, 240, 245, 290, 310, 315, 320, 330, 340, 345, 350, 355, 360, 362, 365, 370, 371, 380, 385, 450, 891.
- [ ] IV. 220, 422, 423, 430, 460, 480, 490, 510, 530, 610, 620, 630, 640, 650, 660, 690, 810, 861-865, 870, 871, 875, 900.
- [ ] V. 150, 152, 153.

3. Title and number, if any, of related cases. (See local rule 40.1(g)). If more than one prior related case has been filed in this district please indicate the title and number of the first filed case in this court.

4. Has a prior action between the same parties and based on the same claim ever been filed in this court?

YES [ ] NO [x]

5. Does the complaint in this case question the constitutionality of an act of congress affecting the public interest? (See 28 USC §2403)

YES [ ] NO [x]

If so, is the U.S.A. or an officer, agent or employee of the U.S. a party?

YES [ ] NO [ ]

6. Is this case required to be heard and determined by a district court of three judges pursuant to title 28 USC §2284?

YES [ ] NO [x]

7. Do all of the parties in this action, excluding governmental agencies of the united states and the Commonwealth of Massachusetts ("governmental agencies"), residing in Massachusetts reside in the same division? - (See Local Rule 40.1(d)).

YES [ ] NO [x]

A. If yes, in which division do all of the non-governmental parties reside?

Eastern Division [ ] Central Division [ ] Western Division [ ]

B. If no, in which division do the majority of the plaintiffs or the only parties, excluding governmental agencies, residing in Massachusetts reside?

Eastern Division [ ] Central Division [ ] Western Division [ ]

8. If filing a Notice of Removal - are there any motions pending in the state court requiring the attention of this Court? (If yes, submit a separate sheet identifying the motions)

YES [ ] NO [ ]

(PLEASE TYPE OR PRINT)

ATTORNEY'S NAME Sarah Chapin Columbia, Esq., Carlos Perez-Albuerne, Esq.

ADDRESS Choate, Hall & Stewart LLP, Two International Place, Boston, MA 02110

TELEPHONE NO. (617) 248-5000

(CategoryForm.wpd - 5/2/05)